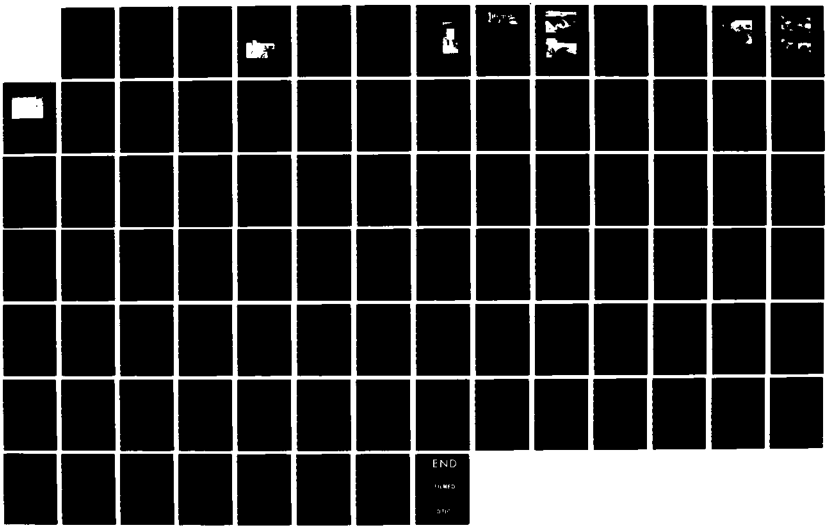
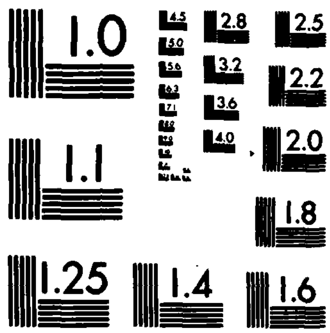
AD-A157 815 INCORPORATION OF ENVIRONMENTAL FEATURES IN FLOOD CONTROL CHANNEL PROJECTS(U) ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS ENVIR.. 3/3

UNCLASSIFIED N R NUNNALLY ET AL. MAY 85 WES/TR/E-85-3 F/G 13/2 NL





MICROCOPY RESOLUTION TEST CHART
ARDS-1963-A

the preceding list (paragraph 345), which are not allowed under present policy. It is clear that no project with a recreation component similar to that of Indian Bend Wash could be built under present policies. This section is confined to discussion of recreation facilities especially suited to flood channel projects and to unusual or innovative designs recommended for environmental reasons. General guidance for the planning and design of recreation facilities is provided in EM 1110-2-400 (OCE 1971b).

Trails

347. Discussion. Trails are the most popular recreational feature on CE flood channel projects. Trails intended for use by hikers and bikers are most often constructed of asphalt or concrete, although other materials are sometimes used. Table 18 lists the types of materials used and some representative costs. On the other hand, equestrian trails are usually graded soil and are correspondingly cheaper to build. In cold climates hiking, biking, and equestrian trails can double as snowmobile trails during winter.

348. Ancillary facilities that are often associated with hike-bike trails include parking and access areas, benches, picnic tables, water fountains, comfort stations, lighting facilities, and fencing. Equestrian trails have many of the same facilities, but also require staging areas with watering troughs.

349. Design considerations. The appropriateness of trails for channel projects is attested to by the fact that almost every project with a recreation component has a trail system. Foot and bicycle trails are used to interconnect recreation areas, connect project facilities to outside areas, tie into existing trail systems, and provide safe walking and riding in a pleasant environment. Trail design and operation should preclude conflicts between different types of users (e.g., equestrians, hikers, and bikers). Fences may be required along trails that pass through industrial neighborhoods or other areas where user safety could be a problem. Barricades should be provided in hazardous areas, and bollards (post and chain barriers) may be required to exclude off-the-road vehicles and other motorized vehicles from trails intended for

pedestrians and cyclists. Trails for motorized vehicles, such as trail bikes and snowmobiles, should be located far enough from sites used for unrelated activities that noise will not be a problem. Trails that tie into existing trail systems should be compatible in appearance and constructed to equivalent standards. Standards for trail construction can be found in National Park Service (1968) and Bureau of Land Management (1965).

350. Surfaces. Walking trails are generally surfaced for all-weather use. Wood chips or gravel can be used in normal traffic areas. In heavy-use areas and on dual-purpose hike-bike trails, asphalt or concrete is suggested. Hard-surfaced walkways and bike trails seemed to have fairly standard designs with compacted subgrades, a layer of gravel or slag, and a 2- to 4-in. layer of concrete or asphalt. An innovative grassed-bituminous trail consisting of 6 in. of slag or crushed stone over a compacted subgrade was proposed for Chartiers Creek (Figure 66).

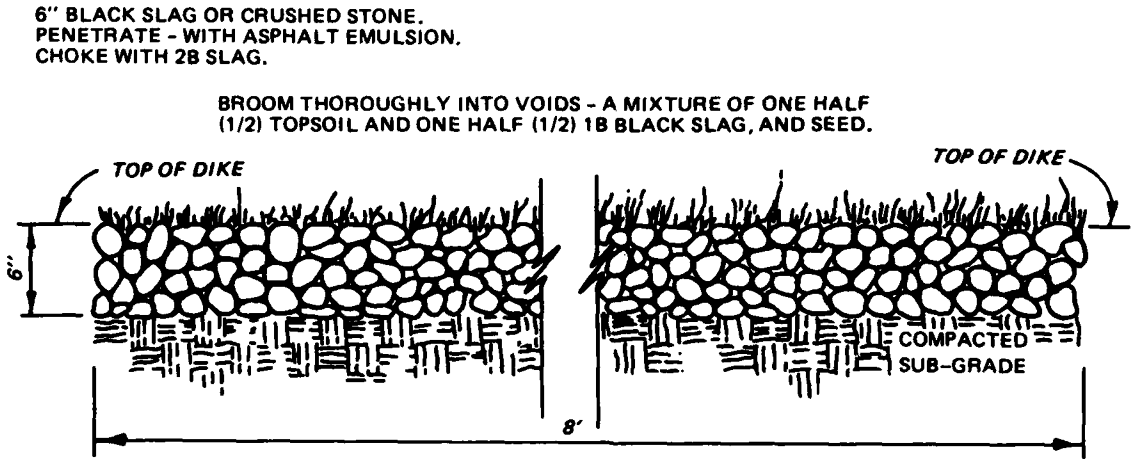


Figure 66. All-weather trail design, Chartier's Creek, Pennsylvania. This unique design consisted of grass planted on a surface paved with slag. (USAED, Pittsburgh 1973, 1974)

The slag was to be penetrated with asphalt emulsion and choked with 2B slag. A mixture of half topsoil and half 1B black slag and seed was to be brushed into the voids to establish the vegetative cover (USAED, Pittsburgh 1973, 1974). The contractor was not able to implement the concept successfully, even though it had been used sucessfully in a local park. When the contractor reached the final stage at which the mixture of topsoil and grass seed was to be swept into the voids, no voids were left, and a rough bituminous path was the result. The walkway in the park supports about a 50 percent cover of grass that is natural in appearance and does not require mowing. Equestrian trails are usually constructed of graded soil. A good system of signs that provide directions, distances, and locations for major points of interest can enhance the value of a trail system. Well-designed signage also can help establish a motif and improve project aesthetics.

351. Extensive trail systems usually require grade separated crossings at street and road intersections for safety reasons. Underpasses that parallel channel alignments are common (Figure 67). Bridges or low water crossings are used where trails intersect channels. Design of these facilities is discussed in paragraph 344. Consideration should be given to access by handicapped persons in designing hiking trails in urban areas.

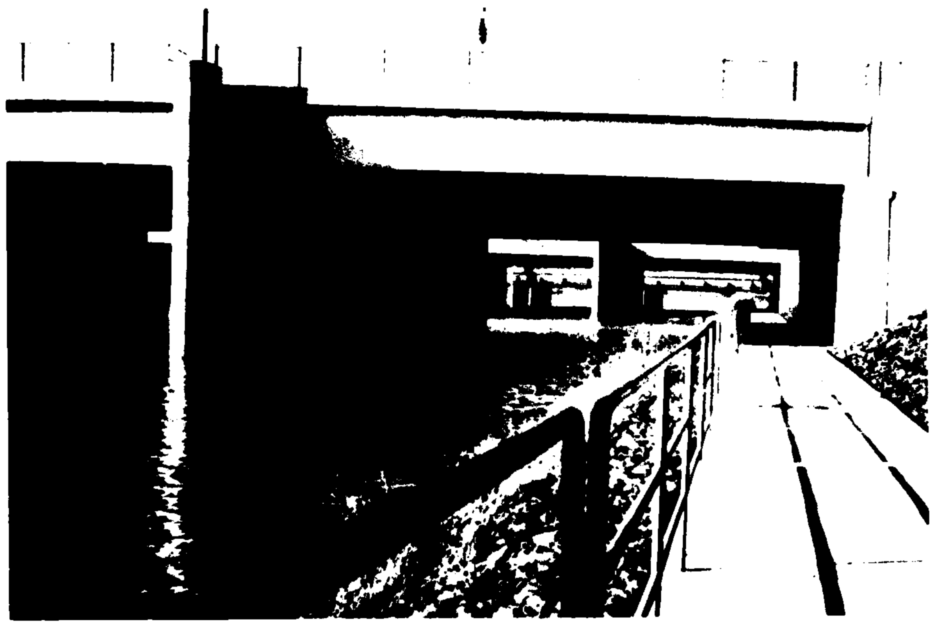


Figure 67. Trail underpass, Fourmile Run, Maryland. For safety reasons, most trails require grade separated crossings where they intersect major streets or thoroughfares.

Playgrounds and playing fields

352. Discussion. Playgrounds and sport facilities are popular components of many flood channel projects that incorporated public parks and greenways. These parks often contained swimming pools, tennis courts, ball diamonds, soccer and football fields, and other facilities built for specific games. Under current CE policy, such facilities are ineligible for Corps participation. General purpose play areas and playgrounds are eligible so long as the playgrounds contain no elaborate equipment (paragraph 345).

353. Design considerations. Local sponsors of urban flood control projects often request recreation plans that include playgrounds and game areas. Though current policy no longer permits construction of special purpose facilities such as tennis courts and softball diamonds, general-purpose playing fields can be constructed. Children's playgrounds can also be included so long as they do not employ very elaborate designs. Playgrounds and playing fields are well suited for projects that include parks and campgrounds.

Nature areas and trails

354. Discussion. Severed bendways, cutoff islands, and wetlands maintained in their natural state and areas developed for wildlife habitat are often used as nature study areas. Trails constructed in nature areas are usually primitive in design and require little more than vegetative clearing and marking, although if they experience heavy use, wood chips, gravel, or other cover may be required to prevent erosion. Nature areas are sometimes designated as wildlife conservation areas and may be fenced for protection. Facilities found at nature areas range from none in some cases to parking areas, restrooms, interpretive displays, and signs identifying features of interest.

355. Design considerations. Locations that are best suited for development as nature areas are natural areas that support unusual or unique ecosystems, which possess a variety of natural conditions (geology, soils, etc.), or which are rich in biological diversity. Nature trails with interpretive displays and signs identifying features of interest have increased value as outdoor classrooms and learning resources.

Trails, signs, and structures should not detract from the natural theme of nature areas. "Rustic" designs are often favored (Figure 68).

Fishing access areas

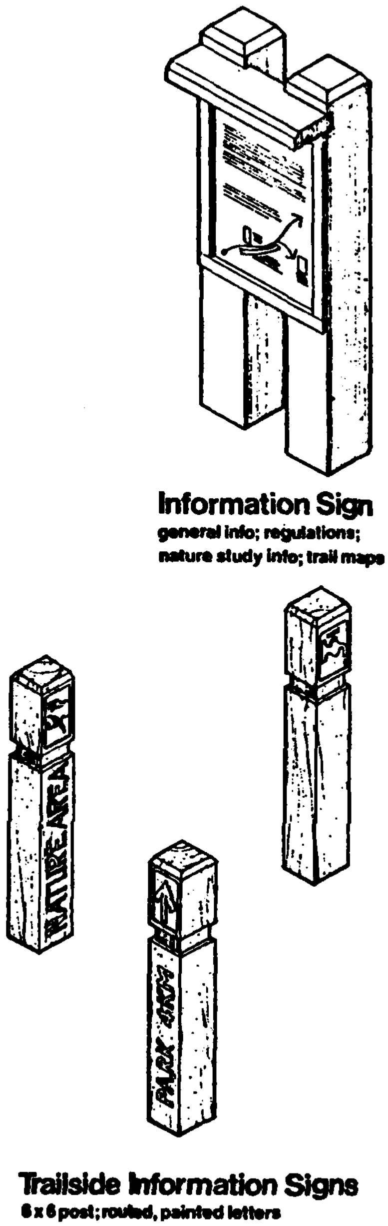
356. Discussion. Fishermen are often attracted to weir pools, stilling basins, and other locations with deep water or good fish habitat. Developed fishing access areas encourage fishing activity while protecting banks and streamside vegetation at other locations from traffic. The Chillicothe Local Protection Project (USAED, Huntington 1975) included $15,000 (1973 price level) to build three simple structures at popular bank fishing sites (Figure 69). The design for the Hocking River at Logan, Ohio, includes an eight-car parking lot and a 1000-ft streamside trail for fishing access (USAED, Huntington 1978).

357. Design considerations. Fishing access areas are usually located at easily accessible pools or structures that attract fish. Access areas may include parking space, boat ramps, water supply and sanitary facilities, trails, and structures. Fishing structures can consist of platforms, piers, or bulkheads such as the one shown in Figure 69. For safety reasons, fences or railings should be provided along platforms or steep banks.

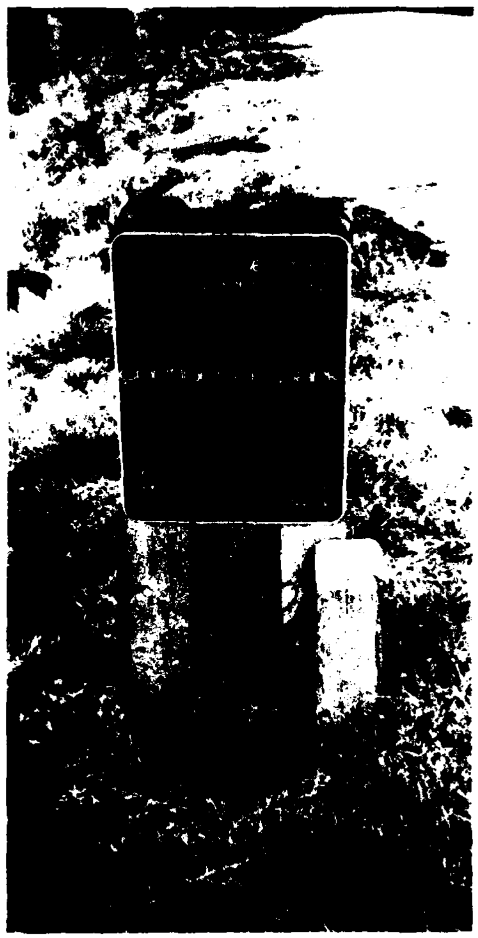
Boating, canoeing, and rafting

358. Discussion. Recreational boating is a popular activity on many flood control channels. If heavy boating use is anticipated, channels should be designed to provide adequate access, suitable low flow depths, and as few obstructions as possible. Minimum dimensions of low flow channels that will accommodate rowboats and canoes are discussed in paragraph 128. Sills and fish habitat structures should be designed so that they will not present obstacles and danger to boaters during low flow conditions, and safe portages should be provided around obstacles such as drop structures and weirs. Appropriate warning signs are needed upstream of such structures. Boating is normally prohibited when discharges exceed a certain amount.

359. It is often possible to modify dams and other structures to allow passage of canoes and rafts. A fabridam located on a reach of the South Platte River downstream of a proposed CE channel project was



a. Wooden signs with routed painted letters blend well with natural settings such as nature areas and trails (after USAED San Francisco 1979)



b. Platte River Greenway trail sign

Figure 68. Information signs

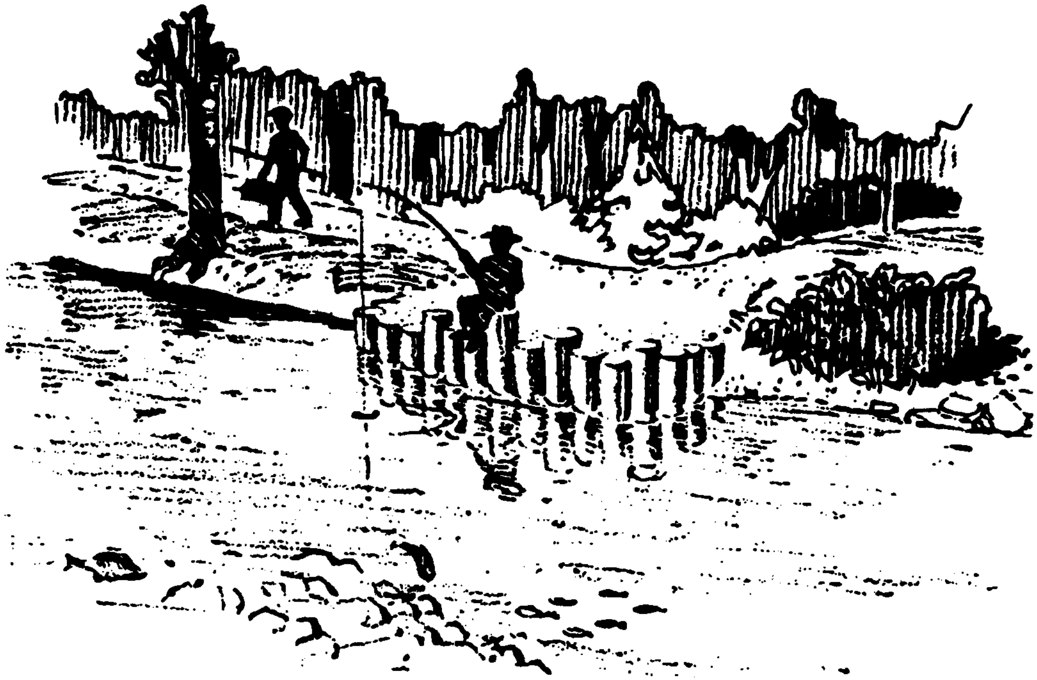


Figure 69. Bank fishing structure. Three of these bulkhead-type structures are planned for the Chillicothe Local Protection Project. (USAED, Huntington 1975)

modified in 1977, at a cost of $140,000, to allow passage by skilled boaters. The boat chute is a concrete and metal slide hinged at the base and resting on the inflatable rubber dam (Figure 70). A second boat chute, designed to accommodate novice boaters and inner tubes, was constructed further downstream on the South Platte in 1975. The Confluence Park chute consists of 12 pools and weirs dropping a total of 10 ft over a run of 330 ft (Figure 71). Flow is regulated by a fabric dam at the upstream end. However, the flow regulation is for water rights stipulations, not boating. "Carry-down" boat ramps are provided at numerous access points along the stream.

360. Recreational boating on streams has increased in popularity in recent years. A 1980 survey of whitewater boating in Colorado revealed that boating use days on the South Platte River through Denver increased from 1500 days in 1976 to 2900 days in 1980 (Environmental Research and Technology 1980). This indicates that facilities such as the

Figure 70. Zuni boat chute, South Platte River, Denver. The rubber fabridam has been modified with a concrete and metal slide to allow passage of canoes and rafts.

Figure 71. Confluence Park boat chute, South Platte, River, Denver. Confluence Park chute consists of a series of 12 pools and weirs that drop 10 ft over a run of 330 ft. Poles mark a kayak slalom course.

Confluence Park boat chute included in CE projects could attract large numbers of users. Flood control channels are often well suited for boatways because of public control of streamside areas.

361. Design considerations. Studies should be undertaken to ensure that flows and water quality are adequate before boatways are planned for flood channels. A whitewater boat chute similar to the one on the South Platte can be provided on flood channels with moderately steep reaches that fall several feet over a relatively short distance. Boat chutes are simple to design, consisting of a series of low rock sills (notched or unnotched) or paired flow deflectors that drop 6 to 12 in. each. Paddleways can be developed on streams with low gradients. If necessary, water depths can be increased by using low flow subchannels or by constructing a series of water control structures to create pools that extend from the base of one structure to the crest of the next structure downstream.

362. Development of successful whitewater streams and paddleways requires that weirs, drop structures, and other barriers be bypassed or modified for boat passage, or that safe portages be provided around those that cannot be modified. Appropriate warning signs are needed upstream of boating hazards, obstacles, and boat chutes. For safety reasons, all boating is usually prohibited when discharges exceed a certain amount. Provision should be made for indicating unsafe discharges. Clearly marked staff gages or removable warning signs should be located at all boating access points. A sufficient number of access points with adequate parking must be provided for launching boats.

Scenic overlooks

363. Description. Scenic overlooks are often planned for accessible sites with attractive views. Parking areas are usually provided at overlooks, and some also have picnic facilities, restrooms, and associated facilities. Overlooks are relatively inexpensive compared to some other recreational facilities, but they can effectively enhance project visitation.

364. Design considerations. Overlooks should be located at sites that provide attractive views of flood channels and the surrounding area.

Overlook parking areas should contain a minimum of 10 spaces (10 by 20 ft), but no more than 30 (OCE 1971b). Additional facilities that may be included are buildings, covered observation platforms, benches, restrooms, water supplies, trash receptacles, and signs or displays that describe the nature and extent of the project.

Campgrounds and picnic areas

365. Discussion. Picnic areas are the second most often included recreational facility found on CE channel projects. Although some picnic areas contain little more than tables, benches, and trash cans, others include shelters, grills, restrooms, parking areas, lights, etc. Small picnic areas are often placed at scenic overlooks and at attractive areas along trails. Large picnic areas are most often associated with urban parks and campgrounds.

366. Few campgrounds were found on the projects surveyed for this report, despite the fact that they are listed as one of the basic recreation facilities that facilitate public use and enjoyment of project resources. One reason is that so many of the flood channel projects are found in urban areas where other types of facilities are in greater demand and are more appropriate.

367. Design considerations. Water resource projects often contain an abundance of sites suited for development as picnic or campground areas, and these facilities are popular visitor attractions. Facilities located in flood-prone areas should have floodproof designs or be removable during flood season, as in the design for Mississippi River State Park (USAED, Memphis 1974). Guidance on selecting numbers and types of facilities based on anticipated use and on layout and placement of facilities is available in EM 1110-2-400 (OCE 1971b). Additional guidance can be found in American Camping Association (1965), National Recreation and Park Association (1961), and State of Michigan Department of Natural Resources (undated).

Historic sites and structures

368. Description. CE regulations require that significant historic sites or resources be considered in formulating recommendations for project authorization and implementation (OCE 1982c). Where

historic sites exist and can be preserved, they can often be incorporated into aesthetic and recreational plans as centers of attraction for local citizens and tourists. The San Antonio River channel contained the remains of the raceway and foundation of an old grist mill built in 1868 (Figure 72). The site, known as Guenther's Upper Mill site, is located

Figure 72. Guenther's Upper Mill site, San Antonio. The old mill site is located in the King William Historic District.

in the King William Historic District, which contains several buildings listed in the National Register of Historic Places. Many houses in the neighborhood have been restored. The flood channel for this reach was designed to minimize disturbance of historic properties in the area and included reconstruction of the mill's raceway and foundation within the flood channel (USAED, Fort Worth 1981).

369. One of the San Antonio River channel improvement projects was implemented to save a historic structure. Espada Acequia is an old Spanish irrigation aqueduct threatened by channel erosion from Six Mile Creek which passed under the structure (Figure 73). A floodway was

a. Circa 1900

b. Circa 1977

Figure 73. Espada Acequia, San Antonio, an old Spanish aqueduct that was being threatened by channel erosion (photos by Fort Worth District)

built to carry flood flows directly to the San Antonio River, while normal flows are diverted through the original Six Mile Creek channel. The headwall of the diversion culvert was veneered with native stone to blend with the old aqueduct and its surroundings (Figure 74) (USAED, Fort Worth 1977).

Figure 74. Native stone veneer, Espada Acequia. The culvert headwall was veneered with natural stone to complement the old stone aqueduct.

370. <u>Design.</u> Guidance for consideration of historic preservation in Civil Works planning studies is provided in ER 1105-2-50 (OCE 1982c). This regulation defines historic property or historic resources as any prehistoric or historic district, site, building, structure, or object included in or eligible for inclusion in the National Register. Historic resources must be taken into account in formulating recommendations for project authorization and implementation. Preservation of significant historic properties through avoidance of effects is preferable to any other form of mitigation (OCE 1982c).

Environmental Considerations in Maintenance

371. Official CE policy for inspection and maintenance of CE flood control channel projects is found in Section 208.10, Title 33 of the Code of Federal Regulations, ER 1130-2-303, Maintenance Guide (OCE 1967b), and ER 1130-2-339, Inspection of Local Flood Protection Projects (OCE 1973). These regulations provide guidelines for project maintenance to ensure efficient and reliable performance. They do not address environmental concerns regarding maintenance.

372. Although local interests are normally responsible for performing CE flood channel maintenance, the CE can influence environmental aspects of maintenance by design of maintenance-related features. Accordingly, design of channel projects should include consideration of maintenance requirements and environmental effects of maintenance policy. In addition, the CE often plays a regulatory role for maintenance of non-Federal projects.

373. The major environmental impacts of channel maintenance are associated primarily with destruction of streambank and streamside vegetative cover, especially woody vegetation, and interference with biologic processes and recreational uses. Many undesirable impacts can be reduced by careful scheduling, minimizing use of heavy equipment, and practicing selective vegetative maintenance.

Scheduling

374. Frequency and timing of maintenance can affect environmental quality. Vegetative maintenance of channels and banks should be performed no more frequently than is required to maintain a hydraulically efficient channel. Measurements made on small channels (up to 50-ft bottom width) by Pickles (1931) and Wilson (1973) indicate Manning roughness coefficients in the range of 0.45 to 0.50 for summer foliage after 1 year's growth (vegetation 3 to 4 ft high). These measurements indicate that the hydraulic efficiency of flood channels designed with roughness values in the range of 0.35 to 0.40 probably would not be seriously impaired by vegetative regrowth in less than two growing seasons. As a general rule, vegetative clearing of channel areas is

probably not needed until channel roughness has increased by 25 percent above the design value. Except in parks and built-up urban areas, vegetation outside the flood conveyance zone may require little or no maintenance other than for access required for channel inspection and maintenance.

375. Proper timing of all channel maintenance can reduce impacts to fish and wildlife and inconvenience to sportsmen and recreationists. Maintenance should be scheduled to avoid fish spawning and migration periods, nesting seasons, prime hunting and fishing seasons, and periods of heavy recreation use.

Equipment access

376. Permanently maintained travelways and access routes should not be included in a project unless essential, and their number and size should be minimized. The need for permanent equipment access can be reduced or virtually eliminated by relying on manual labor and small equipment that is easily manuevered. When hand maintenance and selective removal of vegetation is not feasible, equipment such as mowers mounted on hydraulic booms may be used to mow areas that are difficult to access or that might be damaged by heavy traffic. If hydraulic dredges can be used to remove sediment accumulations, the dredged material can be pumped long distances to disposal or collection areas. In many cases this is superior to the near-channel disposal required for draglines and other types of equipment. Extremely small dredges are commercially available.

Vegetative maintenance practices

377. Vegetative maintenance practices that promote vegetative diversity are preferred. Special care should be taken to avoid disturbing sensitive areas or valuable habitat; dens, burrows, and nesting sites should be avoided. Brush removed from channel areas can be used to provide habitat for small mammals and ground-dwelling birds. However, any brush or other debris deposited on the floodplain should be securely anchored. Hynson et al. (1985) discuss environmentally desirable vegetative maintenance practices for flood control channels and levees. Additional information is provided in the section on selective clearing and snagging (paragraphs 102-121).

378. When vegetation is incorporated in channel designs, funding and effort for adequate and thorough maintenance should be allocated. Ornamental plantings frequently must be replanted, so planting contracts should specify a certain survival rate and require removal of dead plants. Poorly maintained vegetation can be detrimental rather than beneficial to aesthetic and ecological resources. Proposed landscaping maintenance requirements for the Walnut Creek Flood Control Project are presented in Appendix E (USAED, San Francisco 1979). However, if plantings are intended to promote wildlife, often no maintenance is needed once they are well established.

PART V: SELECTION OF ENVIRONMENTAL FEATURES

379. General environmental objectives should be established simultaneously with other project objectives early in the planning process. Several options may exist for achieving a specific environmental objective, as illustrated by Table 19, which is designed as a matrix for selecting environmental features. Columns are environmental objectives and rows are environmental features. Cells containing an X indicate that the environmental feature on that row generally may be an appropriate way to achieve the environmental objective in that column. For example, the aquatic productivity of channels may be increased by incorporating features such as pools and riffles, single-bank construction, bed armor, habitat structures, water control structures, fishways, substrate construction, oxbow and bendway maintenance, scheduling of work to avoid environmentally sensitive periods, and vegetative buffer strips.

380. Although environmental objectives guide the selection process, stream and watershed conditions may influence the successful operation and maintenance of environmental features and must be considered. Table 20 provides a quick way to assess the suitability of an environmental feature. Environmental features are listed across the top, and stream reach and watershed characteristics are listed on the left side. Cells with an X indicate that the environmental feature represented by that column is probably inappropriate for the stream characteristic or watershed conditions represented in that row. Cells with slashes indicate that the feature may be inappropriate, depending on the specific design and precise stream characteristics. For example, instream habitat structures generally are inappropriate for streams that have characteristics such as braided channels, high bedload transport, steep gradients, high discharge, intermittent flow conditions, poor water quality, or no existing fishery, or that drain arid watersheds. In addition, some instream habitat structures may be inappropriate on streams with high suspended loads, bedrock or sand beds, low slopes, discharges between 1,000 and 10,000 cfs, highly variable flows, or

warmwater fisheries; streams that freeze over; or streams that drain urban, agricultural, semiarid, or highly disturbed watersheds. Habitat structure designs that depend on scouring for their effect usually will not work well on bedrock streams, whereas many kinds of designs will not last on mobile, sand bed streams due to undercutting and flanking. The likelihood of success in using a particular design may be difficult to assess unless the environmental feature has been tried under a variety of conditions. The use of Table 20 requires that sufficient data be collected to adequately characterize the stream and its watershed. Section IVA of Appendix B outlines the types of data that should be collected to assess existing conditions and provide the data required for project planning and design.

PART VI: SUMMARY AND RECOMMENDATIONS

Summary

381. Channels modified for flood control often experience severe environmental degradation. The most common problems include erosion and sedimentation that result in property loss, threaten structures, and reduce channel and reservoir capacities; loss of riparian vegetation and the shade, habitat, and organic matter that it provides; loss of aquatic habitat and reduced habitat diversity due to reduced channel length, removal of cover, alteration of substrate, and more uniform flow depths and velocities; loss of terrestrial habitat and reduced diversity caused by extensive clearing, spoil disposal, and altered drainage; and a modified channel that is often aesthetically inferior to the original channel.

382. Many of the impacts encountered in flood control channel modification can be attributed to a failure to recognize that streams do not exist as separate, isolated physical entities that can be manipulated without concern for what happens in adjacent reaches, related systems, or the watershed at large. Instead, streams should be viewed as one part of the fluvial system, which, in turn, strongly interacts with the biological system. When viewed in this systems context, many secondary effects that occur when flood channels are altered are predictable, at least in a qualitative sense. Such predictions are possible because the available knowledge about stream processes and the experience with modified channels are sufficient to establish functional relationships among some of the major components of the fluvial system. These relationships are expressed in Equations 5-21.

383. Many negative environmental impacts of flood channel modifications can be reduced or eliminated by incorporating environmental features into flood control channel designs. Environmental features are defined as any structures or actions employed in planning, designing, constructing, or maintaining flood control channels that improve the net environmental effect. Environmental features may include modifications

of standard techniques, such as selective clearing and snagging or single-bank construction; modified channel designs, such as low flow channels, pools and riffles, and meandering alignments; structures for erosion and sediment control, water level management, and instream habitat; design and maintenance of projects to improve aquatic and terrestrial habitat; inclusion of recreational facilities in project design; and special designs and treatments for aesthetic purposes.

Recommendations

384. Environmental objectives should be given equal consideration with economic objectives in the planning, design, construction, and maintenance of flood control channel projects. Environmental features discussed in Part IV of this report can be used to achieve environmental objectives. Experience with environmental features in flood control channels has been generally positive. However, not all features have performed as anticipated. Experience gained from both failures and successes is valuable in developing design guidance. The design considerations presented in Part IV are based largely on prior experience with the use of environmental features in modified channels. Some features have received little use; thus, there is little basis for evaluation and development of design guidance. In these cases, guidance is based largely on fluvial processes and natural stream geometry.

385. Specific recommendations for improving the environmental quality of flood control channels are as follows:

- a. Formulate general environmental objectives early in the planning process.
- b. Use Table 19 to select potential environmental features for accomplishing environmental objectives.
- c. Eliminate features unsuitable because of stream or watershed conditions (Table 20).
- d. Plan, design, construct, and maintain environmental features according to procedures presented in Part IV of this report. An interdisciplinary team approach that includes representatives from disciplines dealing with the major environmental resources affected by the project is highly recommended.

386. Development of sound design guidance requires feedback on project performance. Designers need to know the conditions under which features perform as expected and the conditions under which they fail. Inspection and maintenance procedures employed on most flood control channel projects are intended to maintain project components in proper functioning condition and to identify and repair deteriorated or failed components. Inspections are not intended to evaluate the overall performance of the project design or of specific components. Continued development and improvement of design guidance for environmental features will depend on the development of procedures for regular inspection and evaluation of environmental features used on CE flood control channel projects. Ideally, standard evaluation procedures should be developed for each type of feature, and evaluations should be incorporated into inspection visits on an annual basis. These evaluations could be made available to investigators charged with extending and modifying official CE guidance.

REFERENCES

Ables, J. H., and Boyd, M. B. 1969. "Low-Water Weirs on Boeuf and Tensas Rivers, Bayou Macon, and Big and Colewa Creeks, Arkansas and Louisiana," Technical Report H-69-13, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Ackers, P., and Charlton, F. G. 1970. "The Geometry of Small Meandering Streams," Proceedings of the Institute of Civil Engineers, Paper 73285, pp 289-317.

Agostini, R., and Papetti, A. 1978. "Flexible Linings for Canals and Canalized Water Courses," S. P. A. Officine, Maccaferri, Bologna, Italy.

Allen, J. R. L. 1977. "Changeable Rivers: Some Aspects of Their Mechanics and Sedimentation," River Channel Changes, K. J. Gregory, ed., John Wiley and Sons, New York, pp 15-45.

American Camping Association. 1965. "Family Camp Standards," Martinsville, Ind.

Amimoto, P. Y. 1978. "Erosion and Sediment Control Handbook," Report No. EPA 440/3-78-003, Division of Mines and Geology, California Department of Conservation.

Anderson, D. R., and Glover, F. A. 1967. "Effects of Water Manipulation on Waterfowl Production," Transactions of the 32nd North American Wildlife and Natural Resources Conference, pp 292-300.

Andrews, E. D. 1976. "River Channel Scour and Fill," Abstracts with Programs, Geological Society of America, Vol 8, No. 6, p 755.

Arner, D. H., et al. 1976. "Effects of Channelization of the Luxapalila River on Fish, Aquatic Invertebrates, Water Quality, and Furbearers," Report No. FWS/OBS-76/08, Office of Biological Services, Fish and Wildlife Service, U. S. Department of the Interior, Washington, D. C.

Arthur D. Little, Inc. 1973. Report on Channel Modifications, U. S. Government Printing Office, Washington, D. C.

Bagnold, R. A. 1960. "Some Aspects of the Shape of River Meanders," Professional Paper 282-E, Geological Survey, U. S. Department of the Interior, Washington, D. C.

Barclay, J. S. 1980. "Impact of Stream Alterations on Riparian Communities in Southcentral Oklahoma," Report No. FWS/OBS-80/17, Office of Biological Services, Fish and Wildlife Service, U. S. Department of the Interior, Washington, D. C.

Barnes, H. H., Jr. 1967. "Roughness Characteristics of Natural Channels," Water-Supply Paper 1849, Geological Survey, U. S. Department of the Interior, Washington, D. C.

Barton, J. R. 1980. "Stream Channelization and Fish Habitat," Recreation Planning and Development, 1st National Conference, American Society of Civil Engineers, Vol 1, pp 297-307, Snowbird, Utah.

Barton, J. R., and Cron, F. W. 1979. "Restoration of Fish Habitat in Relocated Streams," Report No. FHWA-1P-79-3, Federal Highway Administration, U. S. Department of Transportation, Washington, D. C.

Barton, J. R., and Winger, P. V. 1973. "A Study of the Channelization of the Weber River, Summit County, Utah," Utah Division of Wildlife Resources and Utah State Department of Highways.

__________. 1974. "Stream Rehabilitation Concepts," Research Report submitted to Utah State Department of Highways.

Barton, J. R., et al. 1971. "The Effects of Highway Construction on the Hydrology and Hydrobiology of the Weber River near Henefer," Final Report to the Utah Division of Fish and Game and the Utah Department of Highways, College of Physical and Engineering Sciences, Brigham Young University, Provo, Utah.

Beckett, Jackson, Raeder, Inc. 1981. Soil Erosion and Sedimentation Control, Environmental Design Press, Reston, Va.

Bell, M. C. 1973. "Fisheries Handbook of Engineering Requirements and Biological Criteria," Fisheries-Engineering Research Program, U. S. Army Engineer Division, North Pacific, Portland, Oreg.

Best, L. B., et al. 1978. "Effects of Stream Channelization on Land-Use Practices in Iowa," Iowa State Journal of Resources, Vol 52, No. 4, pp 411-423.

Bilby, R. E., and Likens, G. E. 1980. "Importance of Organic Debris Dams in the Structure and Function of Stream Ecosystems," Ecology, Vol 61, No. 5, pp 1107-1113.

Bingham, C. R. 1982. "Benthic Macroinvertebrate Study of a Stone Dike," Environmental and Water Quality Operational Studies Information Exchange Bulletin, Vol E-82-4, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Binns, N. A., and Eiserman, F. M. 1979. "Quantification of Trout Habitat in Wyoming," Transactions of the American Fisheries Society, Vol 108, No. 3, pp 215-228.

Bowie, A. J. 1981. "Streambank Channel Stability; Appendix C, Investigations of Vegetation for Stabilizing Eroding Streambanks, Project Objective 2," U. S. Department of Agriculture Sedimentation Laboratory, Oxford, Miss.

Branson, F. A. 1981. Rangeland Hydrology, 2d ed., Kendall-Hunt, Dubuque, Iowa.

Brevard, J. A. 1975. "Hydraulic Design of Riprap Structure for Gradient Control," Paper 75-2022, 68th Annual Meeting of American Society of Agricultural Engineers, Davis, Calif.

Brice, J. C. 1981. "Stability of Relocated Stream Channels," Technical Report FHWA/RD-80/158, Federal Highway Administration, U. S. Department of Transportation, Washington, D. C.

Brinson, M. M., et al. 1981. "Riparian Ecosystems: Their Ecology and Status," Report No. FWS/OBS-81/17, Office of Biological Services, Fish and Wildlife Service, U. S. Department of the Interior, Kearneysville, W. Va.

Broderson, J. M. 1973. "Sizing Buffer Strips to Maintain Water Quality," Master's Thesis, University of Washington, Seattle, Wash.

Brown, S. A., McQuivey, R. S., and Keefer, T. N. 1981. "Stream Channel Degradation and Aggradation: Analysis of Impacts to Highway Crossings," Technical Report FHWA/RD-80/159, Federal Highway Administration, U. S. Department of Transportation, Washington, D. C.

Bruk, S., and Volf, Z. 1967. "Determination of Roughness Coefficients for Very Irregular Rivers with Large Floodplains," Proceedings of the Twelfth Congress of the International Association for Hydraulic Research, International Association for Hydraulic Research, Vol 1, pp 95-99.

Bulkley, R. V., et al. 1976. "Warmwater Stream Alteration in Iowa: Extent, Effects on Habitat, Fish and Fish-Food, and Evaluation of Stream Improvement Structures (Summary Report)," Report No. FWS/OBS-76/16, Office of Biological Services, Fish and Wildlife Service, U. S. Department of the Interior, Washington, D. C.

Burch, C. W., et al. 1984. "Environmental Guidelines for Dike Fields," Technical Report E-84-4, prepared by Versar, Inc., for U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Bureau of Land Management, U. S. Department of the Interior. 1965. "Roads Handbook," Washington, D. C.

Burkham, D. E. 1976. "Hydraulic Effects of Changes in Bottom-Land Vegetation on Three Major Floods, Gila River in Southeastern Arizona," Professional Paper 655-J, Geologic Survey, Department of the Interior, Washington, D. C.

Calhoun, A. 1966. Inland Fisheries Management, Resources Agency, California Department of Fish and Game, Sacramento, Calif.

Carline, R. F., and Kloslewski, S. P. 1981. "Responses of Macroinvertebrates and Fish Populations to Channelization and Mitigation Structures in Chippewa Creek and River Styx, Ohio," The Ohio State University Research Foundation, Columbus, Ohio.

Carlston, C. W. 1965. "The Relation of Free Meander Geometry to Stream Discharge and Its Geomorphic Implications," American Journal of Science, Vol 263, pp 864-885.

Cederholm, C. J. 1972. "The Short-Term Physical and Biological Effects of Stream Channelization at Big Beef Creek, Kitsap County, Washington," Master's Thesis, University of Washington, Seattle, Wash.

Chang, H. H., et al. 1982. "Relationships Between Morphology of Small Streams and Sediment Yield," Journal of the Hydraulics Division, American Society of Civil Engineers, Vol 108, No. HY11, pp 1328-1365.

Chow, V. T. 1959. Open Channel Hydraulics, McGraw-Hill, Inc., New York.

Clay, C. H. 1961. Design of Fishways and Other Fish Facilities, Department of Fisheries of Canada, Ottawa, Canada.

Coastal Zone Resources Division, Ocean Data Systems, Inc. 1978. "Handbook for Terrestrial Wildlife Habitat Development on Dredged Material," Technical Report D-78-37, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Collier, C. R., et al. 1964. "Influence of Strip Mining on the Hydrologic Environment of Beaver Creek Basin, Kentucky, 1955-1959," Professional Paper 427-B, Geological Survey, U. S. Department of the Interior, Washington, D. C.

__________. 1971. "Influence of Strip Mining on the Hydrologic Environment of Parts of Beaver Creek Basin, Kentucky, 1955-1966," Professional Paper 427-C, Geological Survey, U. S. Department of the Interior, Washington, D. C.

Cooper, C. O., and Wesche, T. A. 1976. "Stream Channel Modification to Enhance Trout Habitat Under Low Flow Conditions," Water Resources Series No. 58, Wyoming Water Resources Research Institute, Laramie, Wyo.

Cooper, E. L. 1981. "The Impact of Stream Relocation on Fish Populations and Bottom Fauna with Emphasis on Movement of Fishes Through Long Culverts," Institute for Research on Land and Water Resources, Pennsylvania State University, University Park, Pa.

Corbett, E. S., Lynch, J. A., and Sopper, W. E. 1978. "Timber Harvesting Practices and Water Quality in the Eastern United States," Journal of Forestry, Vol 76, No. 8, pp 484-488.

Corning, R. V. 1975. "Channelization: Shortcut to Nowhere," Virginia Wildlife, pp 6-8.

Dale, E. E. 1975. "Environmental Evaluation Report on Various Completed Channel Improvement Projects in Eastern Arkansas," Publication No. 30, Water Resources Research Center, University of Arkansas, Fayetteville, Ark.

Dodge, B. H. 1948. "Design and Operation of Debris Basins," Proceedings, Federal Inter-Agency Sedimentation Conference, 1947, U. S. Department of the Interior, Washington, D. C., pp 274-294.

Dodge, W. E., et al. 1976. "Channelization Assessment, White River, Vermont, Remote Sensing, Benthos, and Wildlife," Report No. FWS/OBS-76/7, Office of Biological Services, Fish and Wildlife Service, U. S. Department of the Interior, Washington, D. C.

Douglas, I. 1974. "The Impact of Urbanization on River Systems," Proceedings of the International Geographical Union Regional Conference, New Zealand Geographical Society, Christchurch, pp 307-317.

Dunne, T., and Leopold, L. B. 1978. Water in Environmental Planning, Freeman, San Francisco, Calif.

Ebert, D. J., and Knight, L. A. 1981. "Management of Warmwater Stream Systems in Holly Springs National Forest, Mississippi," Proceedings of the Symposium on the Fisheries Aspects of Warmwater Streams, Southern Division, American Fisheries Society, pp 382-387.

Edminster, F. C., Atkinson, W. S., and McIntyre, A. C. 1949. "Streambank Erosion Control on the Winooski River, Vermont," Circular No. 837, United States Department of Agriculture, Washington, D. C.

Edwards, C. J. 1977. "The Effects of Channelization and Mitigation on the Fish Community and Population Structure in the Olentangy River, Ohio," Ph. D. Dissertation, Ohio State University, Columbus, Ohio.

Ehlers, R. 1956. "An Evaluation of Stream Improvement Devices Constructed Eighteen Years Ago," California Fish and Game, Vol 42, No. 3, pp 203-217.

Einstein, H. A. 1972. "Sedimentation (Suspended Solids)," River Ecology and Man, R. T. Oglesby, et al., eds., Academic Press, New York, pp 309-318.

Eiserman, F. G., et al. 1975. "Cold Water Handbook for Wyoming," U. S. Soil Conservation Service and Wyoming Game and Fish Department, Cheyenne, Wyo.

Elliott, C. 1982. "Inspection and Maintenance," Lecture N, Streambank Protection Shortcourse Notebook, U. S. Army Engineer Division, Huntsville, Huntsville, Ala.

Ellis, M. C. 1937. "Detection and Measurement of Stream Pollution," U. S. Bureau of Sport Fisheries and Wildlife Bulletin, Vol 48, pp 365-437.

Elser, A. A. 1968. "Fish Populations of a Trout Stream in Relation to Major Habitat Zones and Channel Alterations," Transactions of the American Fisheries Society, Vol 97, No. 4, pp 389-397.

Environmental Protection Agency. 1976. "Quality Criteria for Water," Washington, D. C.

Environmental Research and Technology. 1980. "The 1980 Colorado Whitewater Boating Use and Economic Impact Study," unpublished report, Denver, Colo.

Evans, W. A., and Johnston, B. 1980. "Fish Migration and Fish Passage Problems," Forest Service, U. S. Department of Agriculture, Washington, D. C.

Fajan, O. F. 1981. "Warmwater Stream Management with Emphasis on Bass Streams in Missouri," Proceedings of the Symposium on the Fisheries Aspects of Warmwater Streams, Southern Division, American Fisheries Society, pp 252-265.

Fasken, G. B. 1963. "Guide for Selecting Roughness Coefficient 'n' Values for Channels," Soil Conservation Service, U. S. Department of Agriculture, Lincoln, Nebr.

Ferrell, W. R., and Barr, W. R. 1963. "Criteria and Methods for Use of Check Dams in Stabilizing Channel Banks and Beds," Paper No. 44, Proceedings, Federal Inter-Agency Sedimentation Conference, 1963, Miscellaneous Publication No. 970, U. S. Department of Agriculture, Washington, D. C., pp 376-386.

Fish and Wildlife Service, U. S. Department of the Interior. 1980a. "Habitat Evaluation Procedures," 102 Engineer and Science Manual, Washington, D. C.

__________. 1980b. "Terrestrial Habitat Evaluation Criteria Handbook," Habitat Evaluation Procedures Group, Western Energy and Land Use Team, Denver, Colo.

Forest Service, U. S. Department of Agriculture. 1969. "Wildlife Habitat Improvement Handbook," Forest Service Handbook, 2609 11, Washington, D. C.

Foster, J. E., O'Dell, C. R., and Franco, J. J. 1982. "Development and Maintenance of Typical Navigation Channel, Red River," Technical Report HL-82-6, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Fredrickson, L. H. 1979. "Floral and Faunal Changes in Lowland Hardwood Forests in Missouri Resulting from Channelization, Drainage, and Impoundment," Report No. FWS/OBS-78/91, Office of Biological Services, Fish and Wildlife Service, U. S. Department of the Interior, Washington, D. C.

Funk, J. L., and Robinson, J. W. 1974. "Changes in the Channel of the Lower Missouri River and Effects on Fish and Wildlife," Aquatic Series, No. 11, Missouri Department of Conservation, Jefferson City, Mo.

Gee, M. 1952. "Stream Improvement Handbook," Forest Service, U. S. Department of Agriculture, Washington, D. C.

Gore, J. A., and Johnson, L. S. 1980. "Establishment of Biotic and Hydrologic Stability in a Reclaimed Coal Strip Mined River Channel," Institute of Energy and Environment, University of Wyoming, Laramie, Wyo.

Gorman, O. T., and Karr, J. R. 1978. "Habitat Structure and Stream Fish Communities," Ecology, Vol 59, No. 3, pp 507-515.

Graf, W. L. 1979a. "Catastrophe Theory as a Model for Fluvial Change," Adjustments of the Fluvial System, D. D. Rhodes and G. P. Williams, eds., Kendall-Hunt, Dubuque, Iowa, pp 13-32.

__________. 1979b. "Mining and Channel Response," Annals of the Association of American Geographers, Vol 69, No. 2, pp 262-275.

Gregory, J. D., and Stokoe, J. L. 1980. "Streambank Management," Proceedings of the Symposium on Fisheries Aspects of Warmwater Streams, American Fisheries Society, pp 276-281.

Gregory, K. J., and Walling, D. E. 1973. Drainage Basin Form and Process: A Geomorphological Approach, John Wiley and Sons, New York.

Griggs, G. B., and Paris, L. 1982. "The Failure of Flood Control on the San Lorenzo River, California," Environmental Management, Vol 6, pp 407-419.

Griswold, B. L., et al. 1978. "Some Effects of Stream Channelization on Fish Populations, Macroinvertebrates, and Fishing in Ohio and Indiana," Report No. FWS/OBS-77/46, Office of Biological Services, Fish and Wildlife Service, U. S. Department of the Interior, Washington, D. C.

Gutschick, K. A. 1978. "Lime Stabilization Under Hydraulic Conditions," presented at 4th International Lime Congress, Hershey, Pa., 21-22 September 1978.

Guy, H. P., et al. 1963. "A Program for Sediment Control in the Washington Metropolitan Region," Technical Bulletin 1963-1, Interstate Commission on the Potomac River, Washington, D. C.

Haliburton, T. A., et al. 1975. "Identification and Treatment of Dispersive Clay Soils," U. S. Bureau of Reclamation Contract 14-06-0-7535, Oklahoma State University, Stillwater, Okla.

Hammer, T. 1972. "Stream Channel Enlargement Due to Urbanization," Water Resources Research, Vol 8, No. 6, pp 1530-1540.

Hansen, D. R. 1971. "Stream Channelization Effects on Fishes and Bottom Fauna in the Little Sioux River, Iowa," Stream Channelization: A Symposium, E. Schneberger and J. L. Funk, eds., Special Publication No. 2, American Fisheries Society, pp 29-51.

Harvey, A. M. 1975. "Some Aspects of the Relations Between Channel Characteristics and Riffle Spacing in Meandering Streams," American Journal of Science, Vol 275, pp 470-478.

Harza Engineering Company. 1964. "Feasibility Study of Improved Methods for Riverbank Stabilization," WES Contract Report 3-81, conducted for the U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp III-18 to III-23.

Headrick, M. R. 1976. "Effects of Stream Channelization on Fish Populations in the Buena Vista Marsh, Portage County, Wisconsin," Report No. FWS/OBS-76/24, Office of Biological Services, Fish and Wildlife Service, U. S. Department of the Interior, Washington, D. C.

Heede, B. H. 1966. "Design; Construction, Cost of Rock Check Dams," U. S. Forest Service Research Paper RM-20, U. S. Department of Agriculture, Fort Collins, Colo.

Henderson, F. M. 1966. Open Channel Flow, MacMillan, New York, N. Y.

Henderson, J. E., and Shields, F. D. 1982. "Environmental Considerations for Streambank Protection Projects," Lecture J-3, Streambank Protection Short Course Notebook, U. S. Army Engineer Division, Huntsville, Huntsville, Ala.

__________. 1984. "Environmental Features for Streambank Protection Projects," Technical Report E-84-11, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Hickman, G. D. 1975. "Value of Instream Cover to the Fish Populations of Middle Fabius River, Missouri," Aquatic Series, No. 14, Missouri Department of Conservation, Jefferson City, Mo.

Hines, J. 1982. "Grade Control Structures," Lecture H-1, Streambank Protection Shortcourse Notebook, U. S. Army Engineer Division, Huntsville, Huntsville, Ala.

Holman, J. N., and Geiger, A. F. 1959. "Sedimentation of Lake Bancroft, Fairfax County, Virginia," SCS-TP-136, Soil Conservation Service, U. S. Department of Agriculture, Washington, D. C.

Howard, A., and Bara, J. P. 1976. "Lime Stabilization on Friant-Kern Canal," Publication No. REC-ERC-76-20, Bureau of Reclamation, U. S. Department of the Interior, Washington, D. C.

Huish, M. T., and Pardue, G. B. 1978. "Ecological Studies of One Channelized and Two Unchannelized Wooded Coastal Swamp Streams in North Carolina," Report No. FWS/OBS-78/85, Office of Biological Services, Fish and Wildlife Service, U. S. Department of the Interior, Washington, D. C.

Hunt, W. A., and Graham, R. O. 1975. "Evaluation of Channel Changes for Fish Habitat," Meeting Preprint 2535, American Society of Civil Engineers National Convention, 3-7 November 1975, Denver, Colo.

Hunt, L. J., et al. 1978. "Upland Habitat Development with Dredged Material Engineering and Plant Propagation," Technical Report DS-78-17, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Hydrologic Engineering Center, U. S. Army Corps of Engineers. 1981. "Computer Program 723-X6-L202A, HEC-2 Water Surface Profiles User's Manual," Water Resources Support Center, U. S. Army Corps of Engineers, Davis, Calif.

Hynes, H. B. N. 1970. The Ecology of Running Water, University of Toronto Press, Toronto, Canada.

Hynson, J. R., et al. 1985. "Environmental Features for Streamside Levee Projects," Technical Report in preparation, prepared by Center for Natural Areas, South Gardiner, Maine, for U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Hyra, R. 1978. "Methods for Assessing Instream Flow for Recreation," Report No. FWS/OBS-78/34, Office of Biological Services, Fish and Wildlife Service, U. S. Department of the Interior, Washington, D. C.

Inglis, C. C. 1949. "The Behavior and Control of Rivers and Canals," Research Publication, Poona, 14, India.

Jahn, L. R., and Trefethan, J. B. 1973. "Placing Channel Modifications in Perspective," Proceedings of the National Symposium on Watersheds in Transition, American Water Resources Association, pp 15-21.

Janda, R. J., et al. 1975. "Watershed Conditions in the Drainage Basin of Redwood Creek, Humboldt Co., California, as of 1973," Open File Report No. 75.568, Geological Survey, U. S. Department of the Interior, Washington, D. C.

Kanaly, J. 1975. "Stream Improvement Evaluation in the Rock Creek Fishway, Carbon County (addendum)," Administrative Report for Project 5075-08-6602, Wyoming Game and Fish Department, Fish Division, Cheyenne, Wyo.

Karr, J. R., and Schlosser, I. J. 1977. "Impact of Nearstream Vegetation and Stream Morphology on Water Quality and Stream Biota," Report No. EPA-600/3-77-097, Office of Research and Development, U. S. Environmental Protection Agency, Athens, Ga.

Keller, E. A. 1971. Areal Sorting of Bedload Material: The Hypothesis of Velocity Reversal," Geological Society of America Bulletin, Vol 82, pp 753-756.

__________. 1978. "Pools, Riffles, and Channelization," Environmental Geology, Vol 12, No. 2, pp 119-127.

Keller, E. A., and Swanson, F. J. 1979. "Effects of Large Organic Material on Channel Form and Fluvial Processes," Earth Surface Processes, Vol 4, pp 361-380.

Kennedy, H. D. 1955. "Colonization of a Previously Barren Stream Section by Aquatic Invertebrates and Trout," Progress in Fish Culture, Vol 17, No. 3, pp 119-122.

Keown, M. P. 1981. "Field Inspection of the Fisher River Channel Realignment Project near Libby, Montana," Inspection Report 11, Section 32 Program, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Keown, M. P., et al. 1977. "Literature Survey and Preliminary Evaluation of Streambank Protection Methods," Technical Report H-77-9, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Kerr, K. W., ed. 1983. The Landscape Architecture Catalog File, 1983 Edition, Publication Board of the American Society of Landscape Architects, Washington, D. C.

King, L. R., and Carlander, K. D. 1976. "A Study of the Effects of Stream Channelization and Bank Stabilization on Warmwater Sport Fish in Iowa; Subproject No. 3, Some Effects of Short-Reach Channelization on Fishes and Fish-Food Organisms in Central Iowa Warmwater Streams," Report No. FWS/OBS-76/13, Office of Biological Services, Fish and Wildlife Service, U. S. Department of the Interior, Washington, D. C.

Kuenzler, E. J., et al. 1977. "Water Quality in North Carolina Coastal Plain Streams and Effects of Channelization," Report No. 127, Water Resources Research Institute of the University of North Carolina, Raleigh, N. C.

Lane, E. W. 1947. "The Effect of Cutting Off Bends in Rivers," University of Iowa Studies in Engineering, Proceedings of the Third Hydraulic Conference, J. W. Howe and J. S. McNown, eds., Bulletin 31, University of Iowa, Iowa City, pp 230-240.

Lane, E. W. 1955. "The Importance of Fluvial Morphology in Hydraulic Engineering," American Society of Civil Engineers Proceedings, Vol 81, Paper No. 741, pp 181-197.

Lehigh, D. R., ed. 1983. "Means Site Work Cost Data," Robert Snow Means Company, Inc., Kingston, Md.

Leopold, L. B. 1968. "Hydrology for Urban Land Planning - A Guidebook on the Hydrologic Effects of Urban Land Use," Circular 554, Geological Survey, U. S. Department of the Interior, Washington, D. C.

__________. 1969a. "Landscape Esthetics," Natural History, Vol 78, No. 8, pp 36-45.

__________. 1969b. "Quantitative Comparison of Some Esthetic Factors Among Rivers," Circular 620, Geological Survey, U. S. Department of the Interior, Washington, D. C.

__________. 1973. "River Channel Changes with Time - An Example," Bulletin of the Geological Society of America, Vol 84, pp 1845-1860.

Leopold, L. B., and Wolman, M. G. 1957. "River Channel Patterns - Braided, Meandering, and Straight," Professional Paper 282B, Geological Survey, U. S. Department of the Interior, Washington, D. C.

__________. 1960. "River Meanders," Bulletin of the Geological Society of America, Vol 71, pp 769-794.

Leopold, L. B., Wolman, M. G., and Miller, J. P. 1964. Fluvial Processes in Geomorphology, Freeman, San Francisco, Calif.

Li, R., and Shen, H. W. 1973. "Effect of Tall Vegetation on Flow and Sediment," Journal of the Hydraulics Division, American Society of Civil Engineers, Vol 99, No. HY5, pp 793-814.

Linder, W. M. 1963. "Stabilization of Stream Beds with Sheet Piling and Rock Sills," Proceedings, Federal Inter-Agency Sedimentation Conference, 1963, Miscellaneous Publication No. 970, U. S. Department of Agriculture, Washington, D. C., pp 470-484.

__________. 1982. "Cellular Blocks" and "Synthetic Mattress, Tubing and Clay Blanket," Lectures G-2-d and G-3-d, Streambank Protection Shortcourse Notebook, U. S. Army Engineer Division, Huntsville, Huntsville, Ala.

Little, W. C., and Murphey, J. B. 1981. Stream Channel Stability, Appendix B, Model Study of the Low Drop Grade Control Structures, prepared for the U. S. Army Engineer District, Vicksburg, by the U. S. Department of Agriculture Sedimentation Laboratory, Oxford, Miss.

__________. 1982. "Model Studies of Low Drop Grade Control Structures," Journal of the Hydraulics Division, American Society of Civil Engineers, Vol 108, No. HY10, pp 1132-1146.

Littlejohn, R. 1982. "Soil Stabilization with Lime," Lecture G-4-b, Streambank Protection Shortcourse Notebook, U. S. Army Engineer Division, Huntsville, Huntsville, Ala.

Litton, L. L., and Lohnes, R. A. 1982. "Soil-Cement for Use in Stream Channel Grade Stabilization Structures," Civil Engineering Department, Iowa State University, Ames, Iowa.

Litton, R. B., et al. 1974. Water and Landscape, Water Information Center, Inc., Port Washington, N. Y.

Lull, H. W., and Reinhart, K. G. 1963. "Logging and Erosion on Rough Terrain in the East," Proceedings of the Federal Interagency Sedimentation Conference, 1963, Miscellaneous Publication 970, U. S. Department of Agriculture, pp 43-47.

Lund, J. A. 1976. "Evaluation of Stream Channelization and Mitigation on the Fishery Resources of the St. Regis River, Montana," Report No. FWS/OBS-71/07, Office of Biological Services, Fish and Wildlife Service, U. S. Department of the Interior, Washington, D. C.

Lunz, J. D., Diaz, R. J., and Cole, R. A. 1978. "Upland and Wetland Habitat with Dredged Material: Ecological Considerations," Technical Report DS-78-15, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Maccaferri Gabions of America. 1968. "Stream Improvement Handbook," Publication No. MN-604, Flushing, N. Y.

Maddock, T. 1972. "Hydrologic Behavior of Stream Channels," Transactions of the Thirty-seventh North American Wildlife and Natural Resources Conference, 12-15 March 1972, Wildlife Management Institute, Washington, D. C., pp 366-374.

Mahmood, K., and Shen, H. W. 1971. "Regime Concept of Sediment-Transporting Canals and Rivers," River Mechanics, H. S. Shen, ed., Fort Collins, Colo.

Martin, C. O. 1981. "Habitat Development and Wildlife Management Plan for the Lower Rio Grande Basin, Texas, Flood Control and Major Drainage Project," U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Marzolf, G. R. 1978. "The Potential Effects of Clearing and Snagging on Stream Ecosystems," Report No. FWS/OBS-78/14, Office of Biological Services, Fish and Wildlife Service, U. S. Department of the Interior, Washington, D. C.

May, B. 1972. "Evaluation of Mitigation Measures in Fisher River, Wolf Creek, and Fortine Creek, 1969-1972," State of Montana Fish and Game Department, Helena, Mont.

Maynord, S. T. 1978. "Practical Riprap Design," Miscellaneous Paper H-78-7, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

__________. 1982. "General Requirements for Streambank and Streambed Protection," "Single Component Revetment General Requirements," and "Riprap Blanket," Lectures E, G-2-a, G-2-6, Streambank Protection Short-course Notebook, U. S. Army Engineer Division, Huntsville, Huntsville, Ala.

McCall, J. D., and Knox, R. F. 1978. "Riparian Habitat in Channelization Projects," Proceedings of the Symposium on Strategies for Protection and Management of Floodplain Wetlands and Other Riparian Ecosystems, General Technical Report GTR-WO-12, Forest Service, U. S. Department of Agriculture, Washington, D. C.

McClellan, T. J. 1970. "Fish Passage Through Highway Culverts," Office of Engineering, Federal Highway Administration, U. S. Department of Transportation, Portland, Ore.

McConnell, C. A., et al. 1980. "Stream Renovation Alternatives: The Wolf River Story," Journal of Soil and Water Conservation, Vol 35, No. 1, pp 17-20.

McIntire, C. D., and Colby, J. A. 1978. "A Hierarchical Model of Lotic Ecosystems," Ecological Monographs, Vol 48, No. 2, pp 167-190.

McMahon, L. A. 1980. "1981 Dodge Guide to Public Works and Heavy Construction Costs," McGraw-Hill Information Systems Co., New York, N. Y.

Meehan, W. R. 1971. "Effects of Gravel Cleaning on Bottom Organisms in the Southern Alaska Streams," Progress in Fish Culture, Vol 33, No. 2, pp 107-111.

Melhorn, W. M., et al. 1975. "Landscape Aesthetics Numerically Defined (Land System): Application to Fluvial Environments," Studies in Fluvial Geomorphology, No. 1, Water Resources Research Center, Purdue University, West Lafayette, Ind.

Moore, C. M., Wood, W. J., and Renfro, G. W. 1960. "Trap Efficiency of Reservoirs, Debris Basins, and Debris Dams," American Society of Civil Engineers Proceedings, Vol 86, Paper No. 2374, HY2, pp 69-87.

Motroni, R. 1980. "The Importance of Riparian Zones to Terrestrial Wildlife," Division of Ecological Services, Fish and Wildlife Service, U. S. Department of the Interior, Sacramento, Calif.

National Park Service, U. S. Department of the Interior. 1968. "Park Road Standards," Washington, D. C.

National Recreation and Park Association. 1961. "Guidelines for Campground Development," Bulletin No. 34, Washington, D. C.

Nelson, R. W., Horak, G. C., and Olson, J. E. 1978. "Western Reservoir and Stream Habitat Improvements Handbook," Report No. FWS/OBS-78/56, Office of Biological Services, Fish and Wildlife Service, U. S. Department of the Interior, Washington, D. C.

Newby, F. L. 1971. "Understanding the Visual Resources," Recreation Symposium Proceedings, Northeastern Forest Experiment Station, U. S. Department of Agriculture, Upper Darby, Pa., pp 68-72.

Nunnally, N. R. 1978. "Stream Renovation: An Alternative to Channelization," Environmental Management, Vol 2, No. 5, pp 403-410.

Nunnally, N. R., and Keller, E. 1979. "Use of Fluvial Processes to Minimize Adverse Effects of Stream Channelization," Technical Report No. 144, Water Resources Research Institute, University of North Carolina, Raleigh, N. C.

Office, Chief of Engineers, U. S. Department of the Army. 1967. "Maintenance Guide," Engineer Regulation No. 1130-2-303, Washington, D. C.

__________. 1968. "Erosion Downstream from Stilling Basin End Sills," Engineer Technical Letter No. 1110-2-52, Washington, D. C.

__________. 1969. "Engineering and Design, Architectural Concrete," Engineer Manual No. 1110-2-39, Washington, D. C.

__________. 1970. "Hydraulic Design of Flood Channels," Engineer Manual No. 1110-2-1601, Washington, D. C.

__________. 1971a. "Additional Guidance for Riprap Channel Protection," Engineer Technical Letter No. 1110-2-120, Washington, D. C.

__________. 1971b. "Engineering and Design, Recreation Planning and Design Criteria," Engineer Manual No. 1110-2-400, Washington, D. C.

__________. 1971c. "Engineering and Design, Environmental Quality in Civil Works Projects," Engineer Manual No. 1110-2-38, Washington, D. C.

__________. 1972a. "Landscape Planting at Levees, Floodwalls and Embankment Dams," Engineer Manual No. 1110-2-301, Washington, D. C.

__________. 1972b. "Stilling Basin Design," Engineer Technical Letter No. 1110-2-141, Washington, D. C.

__________. 1973. "Inspection of Local Flood Protection Projects," Engineer Regulation No. 1130-2-339, Washington, D. C.

__________. 1974a. "Design Criteria Feedback Inspections," Engineer Technical Letter No. 1110-3-208, Washington, D. C.

__________. 1974b. "Gabion Channel Control Structures," Engineer Technical Letter No. 1110-2-194, Washington, D. C.

__________. 1978a. "Hydrologic and Hydraulic Engineering for Survey Investigations," Engineer Technical Letter No. 1110-2-230, Washington, D. C.

__________. 1978b. "Interim Report to Congress, Section 32 Program, Streambank Erosion Control Evaluation and Demonstration Act of 1974," Washington, D. C.

__________. 1981a. "Planting Turf," Technical Manual No. 5-830-2, Washington, D. C.

__________. 1981b. "Final Report to Congress. The Streambank Erosion Control Evaluation and Demonstration Act of 1974," Washington, D. C.

__________. 1981c. "Digest of Water Resources Policies and Authorities," Engineer Pamphlet 1165-2-1, Washington, D. C.

__________. 1982a. "Planning; Project Purpose Planning Guidance," Engineer Regulation No. 1105-2-20, Washington, D. C.

Office, Chief of Engineers, U. S. Department of the Army. 1982b. "Planning; Economic Considerations," Engineer Regulation No. 1105-2-40, Washington, D. C.

________. 1982c. "Planning; Environmental Resources," Engineer Regulation No. 1105-2-50, Washington, D. C.

Omernik, J. M. 1976. "The Influence of Land Use on Stream Nutrient Levels," Report No. EPA-600/3-76-014, Environmental Research Laboratory, U. S. Environmental Protection Agency, Corvallis, Oreg.

O'Rear, C. W. 1975. "The Effects of Stream Channelization on the Distribution of Nutrients and Metals," Technical Report No. 108, Water Resources Research Institute of the University of North Carolina, Raleigh, N. C.

Parker, G. 1978. "Self-formed Straight Rivers with Equilibrium Banks and Mobile Bed; Part 1, The Sand-Silt River," Journal of Fluid Mechanics, Vol 89, pp 109-125.

Parker, G., and Andres, D. 1976. "Detrimental Effects of River Channelization," Proceedings of the Symposium on Inland Waters for Navigation, Flood Control, and Water Diversions, American Society of Civil Engineers, pp 1248-1266.

Parrish, J. D., et al. 1978. "Stream Channel Modification in Hawaii, Part D: Summary Report," Report No. FWS/OBS-78/19, Office of Biological Services, Fish and Wildlife Service, U. S. Department of the Interior, Washington, D. C.

Parsons, D. A. 1960. "Effects of Flood Flow on Channel Boundaries," Journal of the Hydraulics Division, American Society of Civil Engineers, Vol 86, No. HY4, pp 21-34.

________. 1963. "Vegetative Control of Streambank Erosion," Proceedings of the Federal Inter-Agency Sedimentation Conference, 1963, Miscellaneous Publication 970, U. S. Department of Agriculture, Washington, D. C.

Pemberton, E. L., and Lara, J. M. 1971. "A Procedure to Determine Sediment Deposition in a Stilling Basin," Sedimentation Investigations Technical Guide Series; Section E, Intake Works and Desilting Basins; Part 2, Settling Basins, U. S. Department of the Interior, Washington, D. C.

Petryk, S., and Bosmajian, G., III. 1975. "Analysis of Flow Through Vegetation," Journal of the Hydraulics Division, American Society of Civil Engineers, Vol 101, No. HY7, pp 871-884.

Pickles, G. W. 1931. "Run-Off Investigations in Central Illinois," University of Illinois Bulletin, Vol 29, No. 3.

Pinchot, G. 1947. Breaking New Ground, Harcourt Brace, New York, p 332.

Pistano, R. P., and Wiley, R. W. 1980. "The Green River Rock Projects," Proceedings of the Trout Stream Improvement Workshop, Asheville, N. C., 3-6 November 1980, Forest Service, U. S. Department of Agriculture, Atlanta, Ga., pp 16-19.

Plack, D. 1982. "Soil Stabilization with Cement," Lecture G-4-a, Streambank Protection Shortcourse Notebook, U. S. Army Engineer Division, Huntsville, Huntsville, Ala.

Portland Cement Association. 1971. "Soil-Cement Laboratory Handbook," EB052.06S, Skokie, Ill.

__________. 1975a. "Soil-Cement Slope Protection for Embankments: Planning and Design," IS173.02W, Skokie, Ill.

__________. 1975b. "Soil-Cement Slope Protection for Embankment: Construction," IS167.02W, Skokie, Ill.

__________. 1977. "Suggested Specifications for Soil-Cement Base Course," IS008.10S, Skokie, Ill.

__________. 1979. "Soil-Cement Construction Handbook," EB003.09S, Skokie, Ill.

Possardt, E. E., et al. 1976. "Channelization Assessment, White River, Vermont; Remote Sensing, Benthos, and Wildlife," Report No. FWS/OBS-76/07, Office of Biological Services, Fish and Wildlife Service, U. S. Department of the Interior, Washington, D. C.

Prellwitz, O. M. 1976. "Effects of Stream Channelization on Terrestrial Wildlife and Their Habitats in the Buena Vista Marsh, Wisconsin," Report No. FWS/OBS-76/07, Office of Biological Services, Fish and Wildlife Service, U. S. Department of the Interior, Washington, D. C.

Ramser, C. E. 1929. "Flow of Water in Drainage Channels," Technical Bulletin No. 129, U. S. Department of Agriculture, Washington, D. C.

Ree, W. O., and Palmer, V. J. 1949. "Flow of Water in Channels Protected by Vegetative Linings," Technical Bulletin 967, U. S. Department of Agriculture, Washington, D. C.

Santos-Cayudo, J., and Simons, D. B. 1972. "River Response," Environmental Impact on Rivers, H. W. Shen, ed., Fort Collins, Colo., pp 1-1 to 1-25.

Saunders, P. A., and Grace, J. L., Jr. 1981. "Channel Control Structures for Souris River, Minot, North Dakota," Technical Report HL-81-3, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Schlosser, I. J., and Karr, J. R. 1980. "Determinants of Water Quality in Agricultural Watersheds," Research Report No. 147, Water Resources Center, University of Illinois at Urbana-Champaign, Urbana, Ill.

Schmidgall, T. 1982. "Gabions," Lecture G-3-c, Streambank Protection Shortcourse Notebook, U. S. Army Engineer Division, Huntsville, Huntsville, Ala.

Schumm, S. A. 1969. "River Metamorphosis," Journal of the Hydraulics Division, American Society of Civil Engineers, Vol 95, No. HY1, pp 255-273.

__________. 1977. The Fluvial System, John Wiley and Sons, New York.

Scobey, F. C. 1939. "Flow of Water in Irrigation and Similar Canals," Technical Bulletin No. 652, U. S. Department of Agriculture, Washington, D. C.

Shahjahan, M. 1970. "Factors Controlling the Geometry of Fluvial Meanders," Bulletin of the International Association of Scientific Hydrology, Vol 15, No. 3, pp 13-24.

Sheppard, R. J., and Newman, S. 1979. "Prototype Visual Impact Assessment Manual," prepared for Land Use and Landscape Planning Methodology Research Unit, Pacific Southwest Forest and Range Experiment Station, Berkeley, Calif.

Shields, F. D., Jr. 1982. "Environmental Features for Flood Control Channels," Technical Report E-82-7, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

________. 1983. "Design of Habitat Structures for Flood Control Channels," Journal of the Water Resources Planning and Management Division, Vol 4 (Oct 1983), American Society of Civil Engineers.

Shields, F. D., Jr., and Palermo, M. R. 1982. "Assessment of Environmental Considerations in the Design and Construction of Waterway Projects," Technical Report E-82-8, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Shoemaker, J. 1981. Returning the Platte to the People, Greenway Foundation, Denver, Colo.

Simmons, C. E., and Watkins, S. A. 1982. "The Effects of Channel Excavation on Ground-Water Levels and Water Quality in the Black River Basin near Dunn, North Carolina" in preparation, Water-Resources Investigations report, Geological Survey, U. S. Department of the Interior, Raleigh, N. C.

Simons, D. B. 1971. "River and Canal Morphology," River Mechanics, H. S. Shen, ed., Fort Collins, Colo.

Simons, D. B., et al. 1980. Watershed and Stream Mechanics, Research Institute of Colorado, Fort Collins, Colo.

Simpson, P. W., et al. 1981. "Manual of Channelization Impacts on Fish and Wildlife," Fish and Wildlife Service Contract No. 14-16-0009-80-066, Office of Biological Services, Fish and Wildlife Service, U. S. Department of the Interior, Washington, D. C.

Smardon, R. C. 1981. "Final Project Report, Development of Visual Activity Classification and Advance Testing on Visual Impact Assessment Manual Procedures, PSW Cooperative Agreement PSW-80-0005," Report to the Land Use and Landscape Planning Methodology Research Unit, Pacific Southwest Forest and Range Experiment Station, Berkeley, Calif.

Smith, H. K. 1978. "An Introduction to Habitat Development on Dredged Material," Technical Report DS-78-19, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Soil Conservation Service, U. S. Department of Agriculture. 1947. "Handbook of Channel Design for Soil and Water Conservation," Technical Paper No. 61, Washington, D. C.

_________. 1968. "National Engineering Handbook," Washington, D. C.

_________. 1973. "Guide for Sediment Control on Construction Sites in North Carolina," Raleigh, N. C.

_________. 1974. "Final Work Plan for Watershed Protection, Flood Prevention and Recreational Development, Lower Little Black Watershed, Butler and Ripley Counties, Missouri, Clay County, Arkansas," Lincoln, Nebr.

_________. 1975. "Prairie Creek (Vigo) Watershed Project, Indiana," Final Environmental Impact Statement, Indianapolis, Ind.

_________. 1977. "Design of Open Channels," Technical Release No. 25, Washington, D. C.

Soil Conservation Society of America. 1982. Sources of Native Seeds and Plants, Ankeny, Iowa.

Sokolov, Y. N. 1981. "Hydraulic Resistance of Floodplains," Water Resources, Vol 7, No. 6, pp 563-572. (Translated from Vodyne Resursy, No. 6, Nov-Dec 1980, pp 143-154.)

Stalnaker, C. B. 1980. "The Use of Habitat Structure Preferenda for Establishing Flow Regimes Necessary for Maintenance of Fish Habitat," The Ecology of Regulated Streams, J. V. Ward, and J. A. Stanford, eds., Plenum Publishing Corp., pp 321-337.

Stalnaker, C. B., and Arnette, J. L. 1976. Methodologies for the Determination of Stream Resource Flow Requirements: An Assessment, Utah State University, Logan, Utah.

State of Michigan, Department of Natural Resources. Undated. "Design Guidelines for Campground Development," East Lansing, Mich.

Tarzwell, C. M. 1932. "Trout Stream Improvement in Michigan," Transactions of the American Fisheries Society, Vol 61, pp 48-57.

_________. 1938. "An Evaluation of the Methods and Results of Stream Improvement in the Southwest," Transactions, Third North American Wildlife Conference, Vol 3, pp 339-364.

Tatum, F. E. 1963. "A New Method of Estimating Debris-Storage Requirements for Debris Basins," Paper No. 89, Proceedings, Federal Inter-Agency Sedimentation Conference, 1963, Miscellaneous Publication No. 970, U. S. Department of Agriculture, pp 886-898.

Thackston, E. L., and Sneed, R. B. 1982. "Review of Environmental Consequences of Waterway Design and Construction Practices as of 1979," Technical Report E-82-4, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Thornes, J. B. 1977. "Hydraulic Geometry and Channel Change," River Channel Changes, K. J. Gregory, ed., John Wiley and Sons, New York, pp 91-100.

Trimble, S. W. 1974. Man-Induced Soil Erosion on the Southern Piedmont, Soil Conservation Society of America, Ankeny, Iowa.

U. S. Army Engineer District, Buffalo. 1979. "Big Creek Flood Control Project, Phase II, General Design Memorandum," Buffalo, N. Y.

__________, Detroit. 1974. "Flood Control on Saginaw River, Michigan, and Tributaries, Flint River at Flint," Letter Report on Project Beautification and Section C-2, Detroit, Mich.

__________, Fort Worth. 1970. "Duck Creek Channel Improvement, Garland, Texas, Trinity River and Tributaries, Texas, Design Memorandum No. 1, General," Fort Worth, Tex.

__________. 1973. "San Antonio River and Tributaries, Texas, San Antonio Channel Improvement, Design Memorandum No. 4, Part III, Construction Unit 5-3 (Apache Creek from Nineteenth Street, Station 131+00 to General McMullen Drive, Station 209+00)," Fort Worth, Tex.

__________. 1975. "San Antonio Channel Improvement, Texas, Feasibility Report for Espada Aqueduct Flood Protection, San Antonio, Texas," Fort Worth, Tex.

__________. 1977. "San Antonio River and Tributaries, Texas, San Antonio Channel Improvement, Design Memorandum No. 8, Construction Unit 9-1, Espada Acequia Aqueduct Flood Protection (Six Mile Creek Diversion Channel)," Fort Worth, Tex.

__________. 1981. "San Antonio Channel Improvement Project, San Antonio, Bexar County, Texas, Unit 8-3-2, Final Supplement 1 to the Final Environmental Impact Statement," Fort Worth, Tex.

__________, Galveston. 1981. "Taylors Bayou, Texas, Drainage and Flood Control Project, Supplement No. 2 to Design Memorandum No. 1, Describing Changes from DM No. 1, Phase I - Feature Detail, Phase II - General," Galveston, Tex.

__________, Honolulu. 1975. "Final Environmental Statement, Flood Control and Allied Purposes, Iao Stream, Maui, Hawaii," Honolulu, Hawaii.

__________, Huntington. 1975. "Chillicothe, Ohio, Local Protection Project, Design Memorandum No. 1, General Design Memorandum, Phase II, Project Design," Huntington, W. Va.

__________. 1978. "Environmental Statement, Central Ohio Survey for Water Resources Development, Interim Report, Water Resources Projects, Logan and Nelsonville," Huntington, W. Va.

__________, Kansas City. 1972. "Channel Improvement Project, Little Blue River Channel and Lake City Area Improvement, Vicinity of Kansas City, Missouri, Design Memorandum No. 1, General," Kansas City, Mo.

__________, Los Angeles. 1973. "Indian Bend Wash, Maricopa County, Arizona, Final Environmental Statement," Los Angeles, Calif.

__________. 1975. "Los Angeles County Drainage Area, California, Tujunga Wash, Recreation Master Plan," Los Angeles, Calif.

U. S. Army Engineer District, Memphis. 1974. "Mississippi River Flood Control, Mississippi River and Trubitaries, Design Memorandum No. 1-A, Preliminary Master Plan, Recreational Development," Memphis, Tenn.

__________. 1982. "West Tennessee Tributaries Project, Final Supplement to the Final Environmental Impact Statement," Memphis, Tenn.

__________, Mobile. 1979. "Twenty Mile Creek, Tombigbee River and Tributaries," Letter Report, Mobile, Ala.

__________, New York. 1974. "Saw Mill River, New York, Chappaqua Flood Control Project, Modified Plan, Detailed Project Report, Supplement," New York, N. Y.

__________, Pittsburgh. 1973. "Chartiers Creek, Carnegie - Bridgeville Reach, Allegheny County, Pennsylvania, Environmental Improvement, Supplement No. 1 to General Design Memorandum 2, Local Flood Protection," Pittsburgh, Pa.

__________. 1974. "Chartiers Creek, Canonsburg - Houston Reach, Washington County, Pennsylvania, Environmental Improvement, Supplement No. 1 to General Design Memorandum 2, Local Flood Protection," Pittsburgh, Pa.

__________. 1976. "Marianna and Vicinity, Pennsylvania, Local Flood Protection Project, Tenmile Creek, Final Environmental Impact Statement," Pittsburgh, Pa.

__________. 1977. "Sandy Lick Creek Local Flood Protection Project, DuBois, Pennsylvania, Environmental Improvement Unit 2, Supplement No. 2 to General Design Memorandum," Pittsburgh, Pa.

__________, St. Paul. 1970. "Flood Control, Zumbro River, Minnesota, Kellog to Mouth, General Design Memorandum," St. Paul, Minn.

__________. 1975. "Flood Control, Souris River at Minot, North Dakota, Design Memorandum No. 1," St. Paul, Minn.

__________, San Francisco. 1978. "Design Memorandum No. 3, Aesthetic Considerations, Corte Madera Flood Control Project," San Francisco, Calif.

__________. 1979. "Master Plan, Walnut Creek Project, Contra Costa County, California," San Francisco, Calif.

__________. 1980a. "Corte Madera Creek Flood Control Project Unit 4, Revised Environmental Impact Statement (Final)," San Francisco, Calif.

__________. 1980b. "Corte Madera Creek Flood Control Project, Unit No. 4, Design Memorandum No. 2, Supplement No. 1, Revised Final," San Francisco, Calif.

__________, Seattle. 1980. "Placer Creek, Idaho, Flood Control Project, General Design Memorandum," Seattle, Wash.

__________, Vicksburg. Undated. "Flood Control/Mississippi River and Tributaries, Yazoo Basin - Big Sunflower River, Steele Bayou, Item 55-A, Channel Improvement, Issaquena and Washington Counties, Mississippi, Item 55A, Specifications," Vicksburg, Miss.

U. S. Army Engineer District, Wilmington. 1980. "Detailed Project Report on Clearing and Snagging, South River, Sampson and Bladen Counties, North Carolina," Wilmington, N. C.

U. S. Army Engineer Division, Huntsville. 1982. "Streambank Protection Shortcourse Notebook," Huntsville, Ala.

__________, Lower Mississippi Valley. 1980. "A Habitat Evaluation System for Water Resources Planning," Vicksburg, Miss.

__________, Pacific Ocean. 1973. "Namo River, Detailed Project Report for Flood Control," Honolulu, Hawaii.

Vannote, R. L., et al. 1980. "The River Continuum Concept," Canadian Journal of Fisheries and Aquatic Sciences, Vol 37, No. 1, pp 130-137.

Vanoni, V. A., ed. 1975. Sedimentation Engineering, American Society of Civil Engineers, New York, N. Y.

Varga, L. 1982. "Gabion and Crib Walls," Lecture 1-3-b, Streambank Protection Shortcourse Notebook, U. S. Army Engineer Division, Huntsville, Huntsville, Ala.

Virginia Soil and Water Conservation Commission. 1980. "Virginia Erosion and Sediment Control Handbook," 2d ed., Richmond, Va.

Waterways Experiment Station, Environmental Laboratory. 1978. "Wetland Habitat Development with Dredged Material: Engineering and Plant Propagation," Technical Report DS-78-16, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Watts, F. J. 1974. "Design of Culvert Fishways," Water Resources Research Institute, Moscow, Idaho.

Whitaker, G. A., et al. 1979. "Channel Modification and Macroinvertebrate Community Diversity in Small Streams," Water Resources Bulletin, Vol 15, No. 3, pp 874-879.

White, R. J. 1973. "Stream Channel Suitability for Coldwater Fish," Wildlife and Water Management: Striking a Balance, Soil Conservation Society of America, Ankeny, Iowa.

White, R. J., and Byrnildson, O. M. 1967. "Guidelines for Management of Trout Stream Habitat in Wisconsin," Technical Bulletin No. 39, Division of Conservation, Wisconsin Department of Natural Resources, Madison, Wis.

White, W. D., and Wells, S. G. 1979. "Forest Fire Devegetation and Drainage Basin Adjustments in Mountain Terrain," Adjustments to the Fluvial System, D. D. Rhodes, and G. P. Williams, eds., Kendall-Hunt, Dubuque, Iowa, pp 199-223.

Whitlow, T. H., and Harris, R. W. 1979. "Flood-Tolerance in Plants: A State-of-the Art Review," Technical Report E-79-2, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Whitten, C. B., and Patrick, D. M. 1981. "Engineering Geology and Geomorphology of Streambank Erosion; Report 2, Yazoo River Basin Uplands, Mississippi," Technical Report GL-79-7, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Willeke, G. E. 1982. "The George Palmiter River Restoration Techniques," Final Report, Institute of Environmental Sciences, Miami University, Oxford, Ohio.

Wilson, K. V. 1973. "Changes in Floodflow Characteristics of a Rectified Channel Caused by Vegetation, Jackson, Mississippi," Journal of Research of the U. S. Geological Survey, Vol 1, No. 5, pp 621-625.

Winger, P. V., et al. 1976. "Evaluation Study of Channelization and Mitigation Structures in Crow Creek, Franklin County, Tennessee, and Jackson County, Alabama," Soil Conservation Service, U. S. Department of Agriculture, Nashville, Tenn.

Wolman, M. G. 1967. "A Cycle of Sedimentation and Erosion in Urban River Channels," Geografiska Annaler, Vol 49, pp 385-395.

Wydoski, R. S., and Helm, W. T. 1980. "Effects of Alterations to Low Gradient Reaches of Utah Streams," Report No. FWS/OBS-80/14, Office of Biological Services, Fish and Wildlife Service, U. S. Department of the Interior, Washington, D. C.

Yearke, L. W. 1971. "River Erosion Due to Channel Relocation," Civil Engineering, Vol 41, pp 39-40.

Zimmerman, R. C., Goodlett, J. C., and Comer, G. H. 1967. "The Influence of Vegetation on Channel Form of Small Streams," IASH Publication, Vol 75, pp 255-275.

BIBLIOGRAPHY

Office, Chief of Engineers, U. S. Department of the Army. 1967. "Consideration of Aesthetic Values in Water Resources Development," Engineer Regulation No. 1165-2-2, Washington, D. C.

__________. 1968. "Periodic Inspection and Continuing Evaluation of Completed Civil Works Structures," Engineers Regulation No. 1110-2-100, Washington, D. C.

__________. 1969. "Channel and Structures - Protective Measures - Design Conditions," Engineer Technical Letter No. 1110-2-54, Washington, D. C.

__________. 1971a. "Project Operation. Recreation - Resource Management of Civil Works Water Resource Projects," Engineer Regulation No. 1130-2-400, Washington, D. C.

__________. 1971b. "Investigation, Planning, and Development of Water Resources, Recreation Resources Planning," Engineer Regulation No. 1120-2-400, Washington, D. C.

Office, Chief of Engineers, U. S. Department of the Army. 1972. "Design of Recreation Sites, Areas, and Facilities," Engineer Regulation 1110-2-400, Washington, D. C.

__________. 1973. "Planning; Preservation and Enhancement of Fish and Wildlife Resources," Engineer Regulation No. 1105-2-129, Washington, D. C.

__________. 1976. "Environmental Policies, Objectives, and Guidelines for the Civil Works Program of the Corps of Engineers," Engineer Pamphlet 1165-2-501, Washington, D. C.

__________. 1977. "Drop Intake Structures," Engineer Technical Letter No. 1110-2-211, Washington, D. C.

__________. 1979a. "Final Environmental Impact Statement, Flood Control and Related Purposes, South Fork Zumbro River Watershed, Rochester, Olmsted County, Minnesota," Washington, D. C.

__________. 1979b. "Final Environmental Impact Statement, Flood Control Project for Mamaroneck and Sheldrake Rivers Basin (Village and Town of Mamaroneck, N. Y.) and for Byrum River Basin (Greenwich, Connecticut and Port Chester, New York)," Washington, D. C.

__________. 1980. "Water Resources Policies and Authorities, Corps of Engineers Participation in Improvements for Environmental Quality," Engineer Regulation No. 1165-2-28, Washington, D. C.

U. S. Army Engineer District, Baltimore. 1974. "Fourmile Run Local Flood Protection Project, Design Memorandum No. 2, Phase II, General Design Memorandum, Project Design," Baltimore, Md.

__________, Buffalo. 1979. "Ellicott Creek, New York, General Design Memorandum, Phase II (Detailed Design)," Draft Report, Buffalo, N. Y.

__________, Detroit. 1975. "Beautification Letter Report, River Rouge Flood Control Project, Wayne County, Michigan; Landscape Development," Detroit, Mich.

__________, Fort Worth. 1979a. "Boggy Creek, Austin, Texas, Colorado River and Tributaries, Texas," Interim Report, Volume II, Appendix 1, Fort Worth, Tex.

__________. 1979b. "Greenville, Texas, Sabine River Basin Local Flood Protection Project, General Design Memorandum, Supplement No. 2," Fort Worth, Tex.

__________, Huntington. 1976. Design Memorandum No. 1, Supplement, Log Pond Run Diversion," Huntington, W. Va.

__________, Los Angeles. 1973. "Santa Clara River, California, Feature Design Memorandum No. 6, Master Plan for Santa Paula Creek Channel," Los Angeles, Calif.

__________. 1974. "Cucamonga Creek, California, Feature Design Memorandum No. 3, Cucamonga Creek and Tributaries; Recreation Master Plan," Los Angeles, Calif.

U. S. Army Engineer District, Los Angeles. 1976. "Gila River Basin, New River and Phoenix City Streams, Design Memorandum No. 3, General Design Memorandum, Phase I, Plan Formulation," Los Angeles, Calif.

__________. 1978. "Feature Design Memorandum No. 1, The Ballona Creek Bike Trail Recreation Master Plan, Los Angeles County, California," Los Angeles, Calif.

__________, Louisville. 1975. "Mill Creek Local Flood Protection, Design Memorandum No. 3, General Design Memorandum, Phase II, Project Design," Louisville, Ky.

__________, Mobile. 1967. "Tombigbee River and Tributaries, Mississippi and Alabama, Supplement to Design Memorandum No. 1, General Design for Stanefer and James Creeks, Monroe County, Mississippi," Mobile, Ala.

__________. 1982. "Draft Interim Survey Report and Environmental Impact Statement, Three Mile Creek, Mobile, Alabama," Mobile, Ala.

__________, New Orleans. 1973. "Red River Below Denison Dam, Bayou Bodcau and Tributaries, Arkansas and Louisiana - Design Memorandum No. 2 - General Design, Flat River Channel Improvement and Flat River - Loggy Bayou Levee, New Orleans," New Orleans, La.

__________, Omaha. 1976. "South Platte River, Colorado, Chatfield Dam and Lake, Supplement No. 1 to Design Memorandum No. PC-20, Phase I Report, Downstream Channel Improvement," Omaha, Nebr.

__________. 1977a. "Chatfield Lake, Colorado, South Platte River, Chatfield Dam to Denver," Statement of Findings, Omaha, Nebr.

__________. 1977b. "Final Revision to the Chatfield Lake, Colorado Environmental Statement, South Platte River, Chatfield Dam to Denver," Omaha, Nebr.

__________. Portland. 1975. "Design Memorandum, Johnson Creek at Portland and Vicinity, Oregon; Restudy," Portland, Oreg.

__________, St. Paul. 1980. "Flood Control, Roseau River, Minnesota, General Design Memorandum, Supplement No. 2," St. Paul, Minn.

__________. 1982. "General Design Memorandum Phase I and Draft Supplement to the Environmental Impact Statement, Park River at Grafton, North Dakota," St. Paul, Minn.

__________, Vicksburg. 1978. "Design Memorandum No. 18, General Design Memorandum Phase II, Yazoo Basin, MS, Steele Bayou Basin," Vicksburg, Miss.

__________. 1980. "Design Memorandum No. 18, General Design Memorandum Phase II, Supplement A," Vicksburg, Miss.

U. S. Government. "Flood Control Regulations," Code of Federal Regulations, Title 33, Chapter 2, Part 208, U. S. Government Printing Office, Washington, D. C.

Table 1

Channel Projects that Include Environmental Features

Project	Location	CE District/Division or Other Agency	Major Environmental Features
Apache Creek	San Antonio, Texas	Fort Worth District	Special channel linings, low flow channel, low water crossing, recreation, aesthetic treatments
Ballona Creek	Los Angeles County, California	Los Angeles District	Recreation
Black River	Dunn, North Carolina	Wilmington District	One-sided construction with pools
Boggy Creek	Austin, Texas	Fort Worth District	Special channel linings, water level control, riffles, recreation, aesthetic treatments
Bull Creek	Pennsylvania	Pennsylvania Department of Transportation	Sediment control during construction, culvert fishway, fish habitat structures
Byram River	Greenwich, Connecticut Port Chester, New York	New York District	Low flow channel, pools and riffles, single-bank construction, aesthetic treatments, fish habitat structures
Chartiers Creek	Southwestern Pennsylvania	Pittsburgh District	Floodway, flow diversion through natural channel, recreation, aesthetic treatments
Chicod Creek	Pitt County, North Carolina	Soil Conservation Service	Modified clearing and snagging
Chillicothe Local Protection Works	Chillicothe, Ohio	Huntington District	Recreation, aesthetic treatments
Chippewa Creek	Ohio	Soil Conservation Service	Fish habitat structures
Clark Fork	Montana	Montana Highway Department	Meander geometry
Corte Madera Creek	Marin County, California	San Francisco District	Low flow channel, fish habitat devices, pools and riffles, fishways, spawning channel, aesthetic treatments
Crow Creek	Alabama	Soil Conservation Service	Fish habitat structures

(Continued)

(Sheet 1 of 5)

Table 1 (Continued)

Project	Location	CE District/Division or Other Agency	Major Environmental Features
Cucamonga Creek	near Cucamonga, California	Los Angeles District	Debris basins, aesthetic treatments, recreation
Duck Creek	Garland, Texas	Fort Worth District	Sills with low water crossing, recreation, aesthetic treatments
Ellicott Creek	Buffalo, New York, area	Buffalo District	Floodways, recreation, and aesthetic treatments
Espada Acequia	San Antonio, Texas	Fort Worth District	Floodway, historic preservation, aesthetic treatments
Fisher River	Montana	Seattle District	Fish habitat structures
Flint River	Flint, Michigan	Detroit District	Recreation, aesthetic treatments
Fourmile Run	Washington, D. C., area	Baltimore District	Recreation and aesthetic treatments
Hayward Creek	Quincy, Massachusetts	New England Division	Fishway
Hocking River	Logan and Nelsonville, Ohio	Huntington District	Low flow channel, floodway, artificial riffles, habitat structures, aesthetic treatments, recreation
Iao Stream	Maui, Hawaii	Honolulu District	Low flow channel, special channel lining
Indian Bend Wash	Scottsdale, Arizona	Los Angeles District	Low flow channel, erosion control stabilizers, recreation, aesthetic features
Johnson Creek	Oregon	Portland District	Fish ladder
Little Blue River	Independence, Missouri	Kansas City District	One-sided construction, bendway maintenance, floodways, water level control, clay liner for channel, recreation, aesthetic treatments
Little Juniata	Tyrone, Pennsylvania	Baltimore District	Low flow channel, fish ladder, fish habitat structures, riffles and pools
Log Pond	Newark, Ohio	Huntington District	Floodway, artificial riffles, gravel-lined channel

(Continued)

Table 1 (Continued)

Project	Location	CE District/Division or Other Agency	Major Environmental Features
Lower Little Black Watershed	Missouri	Soil Conservation Service	Water level control structures with fish passage
Lower Rio Grande	Texas	Galveston District	Special sediment control features, creation and maintenance of wetlands and terrestrial habitat
Mamaroneck-Sheldrake Rivers	Mamaroneck, New York	New York District	Single-bank construction, low flow channel, pools and riffles, fish habitat structures, aesthetic treatments
Mill Creek Local Protection	Mill Creek, Ohio	Louisville District	Recreation, aesthetic treatments
Mississippi River State Park	Grider, Arkansas	Memphis District	Recreation
Namo River	Guam	Pacific Ocean Division	Combination riprap and grass-lined channel
New Gila River	Phoenix, Arizona	Los Angeles District	Floodway, recreation, sediment control basins, aesthetic treatments
Olentangy River	Ohio	Ohio Department of Transportation	Artificial riffles, fish habitat structures
Park River	Grafton, North Dakota	St. Paul District	Water level control, bendway maintenance, wildlife plantings, wetlands habitat
Placer Creek	Idaho	Seattle District	Debris basins, modified construction techniques
Prairie Creek	Tennessee	Soil Conservation Service	Fish habitat structures
Rapid Creek	South Dakota		Fish habitat structures
Red River	Arkansas	New Orleans District	One-sided construction, water level control, aesthetic treatments
River Rouge	Detroit, Michigan	Detroit District	Recreation, aesthetic treatments

(Continued)

(Sheet 3 of 5)

Table 1 (Continued)

Project	Location	CE District/Division or Other Agency	Major Environmental Features
River Styx	Ohio	Soil Conservation Service	Fish habitat structures
Rock Creek	Wyoming	Wyoming Highway Department	Fish habitat structures
Roseau River	Northwestern Minnesota	St. Paul District	Natural channel maintained as low flow channel, bendway maintenance, fish habitat structures
Sabine River	Greenville, Texas	Fort Worth District	Recreation
San Antonio River	San Antonio, Texas	Fort Worth District	Special construction techniques, historical preservation, recreation, aesthetic treatments
Sandy Lick Creek	DuBois, Pennsylvania	Pittsburgh District	Low flow channel, bendway maintenance, recreation, aesthetic treatments
Santa Paula Creek (terminated)	Ventura County, California	Los Angeles District	Fabridam for water control, fish habitat, recreation, aesthetic treatments
Saw Mill River	Chappaqua, New York	New York District	Low flow channel, pools and riffles, aesthetic treatments
Scajaquada Creek	Buffalo, New York, area	Buffalo District	Floodways, special bank protection, aesthetic treatments
Six Mile Creek (see Espada Acequia)			
Souris River	Minot, North Dakota	St. Paul District	Selective clearing and snagging, water level control structures, recreation, aesthetic treatments
South Fork Zumbro River	Rochester, Minnesota	St. Paul District	Low flow channel, fish habitat improvement, wildlife plantings, floodway with single bank construction, recreation, aesthetic treatments
South Platte	Denver, Colorado	City of Denver	Fabridam, boat chutes, recreation, aesthetic treatments

(Continued)

(Sheet 4 of 5)

Table 1 (Concluded)

Project	Location	CE District/Division or Other Agency	Major Environmental Features
South Platte	Denver, Colorado	Omaha District	Fish habitat, boatway, recreation, aesthetic treatments
Stanefer Creek	Amory, Mississippi	Mobile District	Floodway, water level control, bendway maintenance
Swamp Creek	Ohio	Soil Conservation Service	Fish habitat structures
Swan Lake, Steele Bayou	Western Mississippi	Vicksburg District	Wildlife plantings
Tamalpais Creek (see Corte Madera)			
Taylors Bayou	Beaumont-Port Arthur, Texas, area	Galveston District	Floodway, wetlands habitat with water level control, special construction techniques
Tenmile Creek	East Marianna, Pennsylvania	Pittsburgh District	Low flow channel, gabion riffles, recreation, aesthetic treatments
Threemile Creek	Mobile, Alabama	Mobile District	Water level control, recreation
Tujunga Wash	Los Angeles metropolitan area	Los Angeles District	Recreation, aesthetic treatments
Walnut Creek	Contra Costa County, California	Sacramento District	Floodway with low flow diversion through natural channel, recreation, aesthetic treatments
Weber River	Utah	Utah Highway Department	Fish habitat structures
West Little Pine	Etna, Pennsylvania	Pittsburgh District	Low flow channel, fishway, water level control structures, fish habitat structures
West Tennessee Tributaries	Western Tennessee	Memphis District	Erosion control structures, creation and management of wetlands
Wolf River	Western Tennessee	Soil Conservation Service	Modified clearing and snagging
Zumbro River	Kellogg, Minnesota	St. Paul District	Bendway maintenance

(Sheet 5 of 5)

Table 2

Values of Manning's "n" Reported for Snags and Vegetation

Author	Source of Estimate	Condition	Manning's "n"
Wilson (1973)	50-ft-wide, 12-ft-deep channelized stream near Jackson, Mississippi	Clean	0.022
		After one growing season, summer foliage	0.045
		After 6 yr, summer foliage	0.070
		After 8 yr, winter foliage	0.070
Pickles (1931)	15- to 55-ft drainage ditches in central Illinois	Clear	0.032
		Weeds and bushy willows 3 to 4 ft high	0.050
Burkham (1976)	Gila River at flood	Dense growth of mesquite and saltcedar	0.080
		After eradication	0.024
Bruk and Zolf (1967)	Natural river floodplain	Grassed	0.073
		Tree plantation	0.094
		Naturally forested	0.104
Barnes (1967)	Natural floodplain	Trees up to 6-in. diameter	0.097
Ramser (1929)	Natural river	Sinuous, snag choked, sandy	0.150
Simons*	Loup, Cowlitz, and Snake Rivers, some Alaskan streams	Braided rivers with bars around snags	0.045-0.050
		After snagging	0.035-0.045
USAED, St. Paul (1975)	Souris River	Channel	0.033-0.058
		Overbank areas	0.060-0.120

* Personal Communication, November 1982, D. B. Simons, Associate Dean of Research and Professor of Civil Engineering, Colorado State University, Fort Collins, Colo.

Table 3

Meander Equations*

Equation	Source	Comment
Meander wavelength (λ)		
$\lambda = 6.6W$	Inglis (1949)	U. S. rivers
$\lambda = 10.9W$	Leopold and Wolman (1957)	U. S. river data
$\lambda = 106.1Q_a^{0.46}$	Carlston (1965)	U. S. rivers
$\lambda = 8.2Q_b^{0.62}$	Carlston (1965)	U. S. rivers
$\lambda = 27.4Q_{max}^{0.5}$	Unidentified	Indian rivers, $29,000 < Q < 61,000$ cfs
$\lambda = 36.4Q_d^{0.5}$	Inglis (1949)	Flume data
$\lambda = 37.8Q^{0.5}$	Ackers and Charlton (1970)	Flume data
$\lambda = 234.Q_{max}^{0.5}M^{-0.74}$	Schumm (1969)	U. S. and Australian rivers
Meander amplitude, or width (B)		
$B = 18.6W$	Inglis (1949)	U. S. rivers

(Continued)

* Reproduced from Gregory and Walling (1973). Table originally compiled by Shahjahan (1970). For simplification, exponents differing from unity by 0.03 or less have been dropped, exponents differing from 0.5 by 0.03 or less have been rounded to 0.5, and coefficients have been rounded to the nearest tenth.

Table 3 (Concluded)

Equation	Source	Comment
$B = 57.8Q_{max}^{0.5}$	Unidentified	Indian rivers, 29,000 < Q < 61,000 cfs
$B = 36Q^{0.5}$	Leopold and Wolman (1957)	Flume data
$B = 16Q_d^{0.5}$	Inglis (1949)	Flume data
$B = 65.8Q_b^{0.5}$	Carlston (1965)	U. S. rivers
Radius of curvature (R)		
$R = 2.4W$	Leopold and Wolman (1957)	U. S. rivers
$R = 10W$	Vanoni (1975)	Missouri River

where

λ = meander wavelength

W = channel width

Q_a = mean annual discharge

Q_b = bankfull discharge

Q_{max} = maximum discharge

Q_d = dominant discharge

Q = flume discharge

M = percentage silt clay in channel perimeter

B = meander width

R = radius of curvature

Table 4

Summary of Environmental Impacts, Costs and Maintenance, Channel Linings, and Bank Protection Measures

	Relative Environmental Impacts: Aesthetics	Water quality	Aquatic habitat	Terrestrial habitat	Cost (dollars)	Unit	Base Year	Anticipated Project Life	Relative Maintenance Costs	Failure Rate
Soil binding and stabilization										
Clay blanket (vegetated)	+	+	+	+	2.00*	yd^2	1974	Long	Moderate	Moderate
Lime stabilization (vegetated)	?	?	?	?	7.68	yd^2	1981	Temporary	Measure	
Lime stabilization (unvegetated)	-	?	?	-	4.68	yd^2	1981	Temporary	Measure	
Soil cement blanket	?	?	?	?	3.65-6.43**	ft	1981			
Lime-cement	?	?	?	?	11-17	yd^2	1980			
Vegetation										
Grasses and legumes (seeded)	+	+	+	+	0.18-0.45	yd^2	1980	Long	Low to high	Moderate
Grasses & legumes (sodded)	+	+	+	+	2.50	yd^2	1976	Long	Low to high	Moderate
Woody vegetation	+	+	+	+	0.72-1.80	yd^2	1981	Long	Low to high	Low to moderate
Rigid linings										
Concrete (reinforced)	-	-	-	-	Highly variable			Long	Low	Low
Grouted riprap	±	0	-	-				Moderate	Low	Moderate
Bagged cement & soil-cement	-	0	-	-	58-165**	ft	1981	Moderate	?	Moderate to high
Flexible, porous covers										
Articulated concrete mattress	-	0	-	-				Long	Low	Low
Used tire mats	-	0	?	+	61-683**	ft	1981	Moderate to short	High	High
Manufactured covers										
Filled mats (membranes fill with soil)	-	0	-	-	32.49	yd^2	1981	Short to moderate	High	High
Membranes	-	0	-	-	29.34	yd^2	1981	Short	High	High
Erosion control matting (fiber mesh)	+	+	+	+	0.50-0.65	yd^2	1976	Temporary	Protection	Protection
Monoslab	-	0	-	-	57	ft	1981	Long	Moderate	High
Cellular concrete	+	+	+	0	23	yd^2	1980	Long	Moderate	Moderate to High
Gabion mattress (12 in.)	-	+	+	-	22.50	yd^2	1975	Moderate	Moderate	High
Gravel armor (over riprap)	+	+	+	-	69	yd^2	1978	Long	?	?
Riprap										
Screened (18 in.)	±	+	+	-	15	yd^2	1975	Long	Moderate	Low
Quarry run	±	+	+	-	1.90-16	yd^2	1976	Long	Moderate	Low
Cobble (18 in.)	±	+	+	-	26	yd^2	1974	Long	Moderate	Low
Rubble	-	+	+	-	1.25-3.81	ft	1981	Moderate	Moderate to high	Moderate to high
Longitudinal control										
Fences	-	0	0	0	22-3.41	ft	1981	Moderate	High	Moderate to high
Rockfill	-	0	0	0	14-5.20	ft	1981	Short to moderate	High to moderate	High to moderate
Jacks	-	0	0	0	18-85	ft	1981	Long	Low	Moderate
Anchored trees	0	0	+	0	15-73	ft	1981	Short	Low	Moderate
Concrete cribs	-	0	0	0	6.25	ft	1981	Short	High	Moderate to high
Fence cribs	-	0	0	0	22-3.41	ft	1981	Short	High	Moderate to high
Timber cribs	-	0	0	0	2.33	ft	1981	Short	High	Moderate to high
Tire retards	-	0	0	0	1.50-2.00	ft	1981	Short	High	High
Longard fabric tubes	-	0	-	-	56-2.05	ft	1981	?	?	High

* Does not include seeding of vegetation.
** Higher costs apply to large, navigable streams.
Without irrigation.
Subject to vandalism.

Source: Compiled from OCE (1981b) and flood project survey files. Entries under headings "Relative Environmental Impacts," "Anticipated Project Life," "Relative Maintenance Costs," and "Failure Rate" represent authors' interpretations of data and opinions based on field observations.

Table 5

Permissible Velocities for Channels in Cecil Sandy Loam Having Vegetal Linings of the Kinds Studied*

Channel Lining Species and Condition	Bed Slope percent	Experiments number	Permissible Velocity ft/sec
Bermuda grass:			
Green:			
Long	3	2	*
	10	2	8.0
	20	2	7.0
Short, kept cut	3	None	--
	10	1	9.0
	20	None	--
Short, cut just before test	3	2	*
	10	0	6.5
	20	1	5.0
Dormant:			
Long	3	1	*
	10	1	8.0
	20	1	6.0
Short, kept cut	3	5	8.0
Short, cut just before test	3	1	6.0
Centipede grass:			
Green, long	10	1	9.0
Dormant, long	10	1	8.0
Dallis grass and crabgrass:			
Green, long	6	1	3.5
Kudzu:			
Live, heavy growth:			
Uncut	3	1	4.0
Cut	3	1	3.0
Dormant, heavy growth, uncut	3	1	2.5

(Continued)

* Velocity developed in tests was insufficient to permit estimate.
From Ree and Palmer (1949).

Table 5 (Concluded)

Channel Lining Species and Condition	Bed Slope percent	Experiments number	Permissible Velocity ft/sec
Lespedeza:			
Green:			
Uncut (spring)	3	1	5.5
Long (summer)	6	1	5.5
Short, cut just before test	3	1	4.5
Dead, uncut stubble:			
Spring	3	1	1.0
Fall	3	1	3.5
Sericea lespedeza:			
Green:			
Uncut (not yet woody)	3	2	5.5
Medium long (woody)	6	1	3.0
Short, cut just before test	3	1	3.5
Dormant:			
Uncut	6	1	2.5
Uncut	3	1	3.0
Short, cut previous fall	3	1	3.0
Sudan grass:			
Green, good stand	3	0	4.0
Dead, long	3	1	3.0
Grass mixture:			
Green, long (summer)	3	2	6.5
Green and dormant, short:			
Spring and early summer	3	2	5.0
Fall	3	1	6.5

Table 6

Equivalent Stone Sizes for Bermuda Grass Linings

Condition of Bermuda Grass	Allowable Shear Stress lb/sq ft	Hydraulically Equivalent Stone Diameter in.
Fair stand, short,* dormant	0.9	2
Good stand, kept short, dormant	1.1	2
Good stand, long,** dormant	2.8	5.5
Excellent stand, kept short, green	2.7	5.5
Good stand, long, green	3.2	6.5

* Less than 5 in. high.
** Greater than 8 in. high (from Parsons 1963).

Table 7

Water Diversion Costs on CE Flood Channel Projects

Project	Design Discharge in cfs	Length of Channel Improvement	Cost	Base Year
Little Juniata, Pa.	40,300	13,100 ft	$135,000*	1975
San Antonio River, Tex.	14,300	3,050 ft	$836,000**	1981
New Gila River, Ariz.	36,000	12.9 mi	$ 9,000*	1975
Santa Paula Creek, Calif.	27,000	3.5 mi	$ 54,000*	1971
Byram River, Conn.-N. Y.	6,920	2,700 ft	$ 10,000†	1976
Mamaroneck-Sheldrake Rivers, N. Y.	3,455-4,689	12,000 ft	$150,000†,††	1976
Placer Creek, Idaho	4,600	4,800 ft	$320,000*	1979

* Estimate from General Design Memorandum.
** Contractor's bid.
† Estimate from feasibility report.
†† Estimate does not include Sheldrake River section.

Table 8

Habitat Structures Used on Flood Control Channels

Project	Type of Structure	Size	Cost ($)	Base Year
Little Juniata, Pa.	Boulders	500-2,000 lb	50 ea	1975
Little Juniata, Pa.	Fishway	13,100 ft × 3-20 ft × 2-8 ft (1 × w × d)	1,040,000	1975
Byram River, Conn.-N. Y.	Fish pools	30 ft × 15 ft × 5 ft	1,000 ea	1976
	Boulders or gabions	unspecified	1,000	1976
Mamaroneck-Sheldrake Rivers, N.Y.	Fish pools	40 ft × 20 ft × 5 ft	2,200 ea	1976
South Platte, Colo.	Boulders, individually and in groups - random placement	3- to 5-ft diameter	20,000 ($75-$100 ea)	1983
Tenmile Creek, Pa.	Gabion riffles	40 ft × 10 ft × 1 ft	5,100	1977
Roseau River, Minn. (not implemented)	Triangular deflectors with preformed scour holes, gravel substrate, and boulders	4.5 ft high with scour holes 5 ft deep and 10 ft wide, 18- to 30-in. boulders	36,000 ea	1980

(Continued)

* All costs are Design Memorandum estimates.

Table 8 (Concluded)

Project	Type of Structure	Size	Cost ($)	Base Year
Corte Madera, Calif.	Spawning channel	100 ft × 6 ft × 3 ft, with 2-ft gravel layer	4,600	1978
	Anchored stumps	Unspecified	140-190 ea	1978
	Resting pools	4 ft × 13 ft × 1 ft	700 ea	1978

Table 9

Project Descriptions for Modified Channels with Habitat Structures

Stream	Constructing Agency	Mean Daily Flow, cfs	Channel Capacity, cfs	Channel Slope	Bottom Width ft	Total Length of Modified Reaches, mile
Fisher River, Mont.	Corps of Engineers	520	7,800	0.007	100-125	4.3
Rapid Creek, S. D.	Corps of Engineers	30	500	0.005	30	0.6
Weber River, Utah	Utah Highway Department	255	5,400	0.025-0.047	70	1.6
Olentangy River, Ohio	Ohio Department of Transportation	460	8-10,000	0.0007	120	0.8
Rock Creek, Wyo.	Wyoming Highway Department	82	3,000	0.0145	50	0.2
Crow Creek, Ala.	Soil Conservation Service	200-300	2,000	0.001	30-60	9.2
Prairie Creek, Tenn.	Soil Conservation Service	25	160-640	0.001	8-28	4.0
Chippewa Creek, Ohio	Soil Conservation Service	25	280-1,900	0.0002-0.0008	12-60	10.4
River Styx, Ohio	Soil Conservation Service	15	210-1,000	0.0004-0.0014	8-34	7.9

Source: Shields, 1983.

Table 10

Experiences with Habitat Structures in Modified Channels

Stream	Design	Material	Dimensions, feet: Height Above Grade	Key-in Depth	Crest Width	Spacing	Bed Material	Effectiveness
Fisher River, Mont.	Sills with low flow notch off center	Stones weighing between 200 and 2000 lb with 50% heavier than 100 lb on 1-ft gravel bedding	2	2.5	2	125	Sandy silty gravel with cobbles and boulders	Several structures failed in high flows. Trout populations not enhanced because of increased sediment load and removal of riparian vegetation
Rapid Creek, S. D.	Triangular deflectors, revetments	Stones 1-3 ft in diam in a 6-ft-thick layer over stream gravel	1.5	1.5	N/A	Varies	Gravel, rubble.	Preliminary indications are favorable. Structures are providing good habitat and speeding trout reproduction in the modified reach
Weber River, Utah	Deflectors, sills, random rocks	Gabions, boul-weighing 1-4 tons	1.5-2	2.5-3	4	Varies	Gravel, rubble	Aquatic community in modified reaches similar to unchanged reaches 2-3 years after construction. Recovery aided by presence of several unaltered reaches. Some gabion baskets failed
Olentangy River, Ohio	Sills in low-flow channel. Crest 0.5 ft underwater at normal flow.	Rock mostly 1.5-ft diam or larger over earthen fill	3	0-5	20	840	Clay, silt, sand, and gravel	Reach with structures recovered fish and benthic populations much more quickly than modified reach without structure. Still inferior to unaltered conditions.
Rock Creek, Wyo.	Random rocks in a pattern. Groupings of two and four boulders on alternating sides of channel	Boulders about 5 ft in diam weighing 7-8 tons	4	1	N/A	50-90	Cobble	Trout population recovered from a very limited density to a density comparable to a control (unaltered) section within 2 years
Crow Creek, Ala.	Sills of various design	Riprap, sheet piling, timber. Some sills capped with reinforced concrete	Varies	Varies	Varies	Varies	Gravel, sand, some clay and silt	Some structures placed too high and too close together to create a physically diverse pool-riffle sequence. Structures that produced pools and riffles did provide good habitat
Prairie Creek, Tenn.	Sills with a central gap and preformed scour hole, lined with stone	Stones weighing between 25 and 150 lb with 25%-50% heavier than 100 lb	2	2	2	900	Silty clay, sandy clay, and gravelly sandy clay	Structures provide superior habitat to modified channel without structure
Chippewa Creek, Ohio	Sills similar to Prairie Creek structures	Stones weighing between 10 and 300 lb with 25%-70% heavier than 100 lb	2	1	2	Varies	Silt, sand, and gravel	Fish species diversity, density, and biomass much greater in reaches with structures
River Styx, Ohio	Two sill designs - one similar to Prairie Creek, another similar to Olentangy River. Deflectors	Stones such that 80% are larger than a 0.75-ft-square opening	2	1	2	220	Sand	Minimal effectiveness due to structural structural damage by ice. No pool-riffle sequence developed

Source: Shields, 1983.

Table 11

Costs of Water Control Structures on Corps of Engineers Flood Control Channels

Project	Channel Capacity cfs	Dimensions, ft (Height × Crest Length × Base Width)	Type of Structure	Cost, $	Base Year
Flint River, Mich.	11,400	6 × 100 × 3	Fabridam	501,000*	1976
Threemile Creek, Ala.	12,500	10 × 190 (approximate)	Sheet pile drop structure	260,000**	1982
Red River, Ark.	22,000†	5 × 80 × 2	Concrete weir	24,000	1972
Roseau River, Minn. (not implemented)	7,950	7.3 × 139 × 21.9	Gabion	77,000	1980
		Variable	Unexcavated channel plugs	1,300**	1980
Souris River, N. D.	5,000	10 × 165 × 2	Concrete	200,000*	1975
		3 × 30 × 40	Gabion	50,000*	1975
Stanefer Creek, Miss.	1,750	5.7 × 150	Sheet pile	22,000	1968

* Bid costs. All other costs based on General Design Memorandum estimates.

** Average cost (total cost/number of structures).

† Capacity between levees.

Table 12

Space Requirements for Spawning Fish

Fish Species	Approx. Average Weight, lb	Average Area of Redd sq yd	Area Recommended per Spawning Pair, sq yd
Chinook			
a. summer and fall run	25	6.1	24.0
b. spring run	15	3.9	16.0
Coho	9	3.4	14.0
Chums	10	2.7	11.0
Sockeye	3	2.1	8.0
Chinook (spring run)		13.0	
Pinks	5	0.7	0.7
Trout	1(?)	0.3	2.0

Table 13

Fishways in Modified Channels

Project	Flood Channel Capacity, cfs	Obstacle	Fishway Type	Dimensions, ft (l × w × h)*	Operating Discharge, cfs	Cost	Base Year
Johnson Creek, Oreg.	4400	10-ft drop structure	Hell's Gate	72 × 6 × 12	--	44,000	1973
Corte Madera, Calif.**	6900	6-ft drop structure	Dual Denil	25.5 × 4.5 × 5.5 31.5 × 4.5 × 5.5	10-100 100-240	10,500	1978
Bull Creek, Pa.	Not available	870-ft-long culvert with 0.002 slope	Baffles with rock-lined pools	870 × 21.6 × 1.7	Not available	Not available	
Hayward Creek, Mass.	85	Drop inlet	Pool and weir	26 × 2 × 4.2	0.1-3	3,000	1978

* For Denil and vertical slot structures, H is the height of structure at the downstream end when fully submerged. For weir structures, H is the difference in elevation of highest weir and channel invert below structure.

** Not yet constructed.

Table 14

Corps of Engineers Projects Designed with Aquatic and Wetlands Habitat

Project	Concept	Cost	Year
Zumbro River, Minn.	Plugged meander loop for wildlife habitat. Upstream plug has a flap-gated culvert to allow filling at high flow	$53,000	1971
Souris River, N. D.	Flow maintenance in bendways. Low sills in lower end of bendway for ponding. Gabion and concrete water level structures in bypass channels for water diversion. Sluice-gated barriers at both ends of some oxbows	Less than $50,000 to more than $200,000, depending on type and size of structure	1976
Lower Rio Grande, Tex.	Diking of low swales. Water control structures for Laguna Madre marsh. Diversion ditch	$1,508,000	1982
Taylors Bayou, Tex.	Water ponded in 4 disposal areas for waterfowl. Water level maintained by adjustable weirs. Water control structure	$245,000*	1982

(Continued)

* In lieu of managing two of the disposal areas, local interests, at their own initiative and expense, acquired additional wetlands at an estimated cost of $1,771,000.

Table 14 (Concluded)

Project	Concept	Cost	Year
Little Blue River, Mo.	4 oxbow lakes; 15 flow-through oxbow fisheries	Not available	
West Tennessee Tributaries, Tenn.	21 bendway impoundments; 60 greentree reservoirs	Typical gated corrugated metal pipe $25,000; typical gated drop structure $50,000; typical nongated drop structure $37,000	1981

Table 15

Preservation and Development of Terrestrial Habitat on Flood Control Channel Projects

Project	Habitat Concepts	Cost ($)	Base Year
Byram River, Conn.-N. Y.	Trees and shrubs removed in construction will be replaced with same species or species of equivalent wildlife value	67,000	1976
Mamaroneck-Sheldrake Rivers, N. Y.	Trees and shrubs removed in construction will be replaced with same species or species of equivalent wildlife value	123,000*	1976
Swan Lake, Steele Bayou, Miss.	22 acres of plantings for wildlife food	1,000/acre	1979
	1,200 acres of reforestation	125/acre	1979
Park River, N. D. (proposed)	10 acres planted to trees for wildlife habitat	Not itemized	
South Fork Zumbro River, Minn.	Sharecropping of wildlife food plots; plant mast-producing trees; posting and fencing of wildlife management area	Not itemized	
	Acquisition of 145 acres for mitigation	215,000	1982
Hocking River, Ohio	Adjustments of channel alignment to save a vegetative buffer zone and quality trees and shrubs; wildlife plantings	Not available	
Lower Rio Grande Basin, Tex.	Development of 6057 acres (4088 on disposal areas) of brushland and grassland habitats; 200 miles fencing to protect wildlife management areas	4,395,000	1982

* Estimate does not include costs for Sheldrake River section.

Table 16

Examples of Aesthetic Treatments on CE Flood Channel Projects

Type of Feature	Project	Dimensions	Total or Unit Cost ($)*	Base Year
Special treatments for flood channels and paved surfaces				
Brushed concrete with color	Indian Bend Wash, Ariz.	--	1.50/sq. ft	1977
Forms for molded concrete	Duck Creek, Tex.	**	3,200	1970
	Corte Madera, Calif.	48 in. 22 in.	10,000	1968
	Indian Bend Wash, Ariz.	**	2,500	1977
Exposed aggregate	Indian Bend Wash, Ariz.	--	1.30/sq ft	1977
Decomposed granite	Indian Bend Wash, Ariz.	--	20/sq ft	1977
Cobbles in grout	Indian Bend Wash, Ariz.	--	1.25/sq ft	1977
Cobble paving on granite	Indian Bend Wash, Ariz.	--	3.33/sq ft	1977
Cobblestone paving	Indian Bend Wash, Ariz.	--	1.50/sq ft	1977
Cobble channel bottom	Indian Bend Wash	--	2.90/sq ft	1977
Stone facing for concrete	San Antonio River, Tex.	**		
Seeding of riprap	Corte Madera Creek, Calif.			
Topsoil		--	10/sq yd	1978
Hydromulching		--	0.05/sq ft	1978
Landscaping planters				
Concrete walls	San Antonio River, Tex.	80 10 5	29,000 (B)	1981
Walls and curbing	Flint River, Mich.	2675 lin ft	72,225	1974
	Tujunga Wash, Calif.	25,000/sq ft	37,500	1975
Tree well	Corte Madera, Calif.	**	3,500	1978
Tree protection during construction (includes cost of shims and avoiding trees during construction)	San Antonio River, Tex.	**	1,700/tree (B)	1981
Fencing				
Vinyl-covered chainlink	River Rouge, Mich.	34,172 6 ft	6.50/ft (B)	1976
Wooden rail	Cucamonga, Calif.	13,000 ft	3.00/ft	1973
Redwood	Corte Madera, Calif.	4 ft high	**	
Columns (pilasters) for floodwalls				
Stone faced	San Antonio River, Tex.			
Stone faced	Corte Madera, Calif.	--	40/sq ft	1978
Water displays				
Water cascade	Flint River, Mich.	**	**	
Water cascade	Indian Bend Wash, Ariz.	**	50,000	1977
Reflecting pools	Duck Creek, Tex.	**	1,000 ea	1970
Fountain	Indian Bend Wash, Ariz.	**	39,000	1977
Low Water Crossings				
Concrete sill with stepping stones	Apache Creek, Tex.	**	**	
Grouted sill with stepping stones	Duck Creek, Tex.	**	1,000 ea	1970
Grass and other planted ground covers				
Sodding, topsoil, and fertilizer	Flint River, Mich.	sq yd	2.50/sq yd	1976
Seeding, topsoil, and fertilizer	Flint River, Mich.	sq yd	1.00/sq yd	1976
Turf with auto irrigation	Indian Bend Wash, Ariz.	sq yd	1.50/sq yd	1974
Hydromulched multiseed mixture	South Platte, Colo.	sq yd	0.93/sq yd	1983
Seeding without irrigation	West Tennessee Tributaries	sq yd	0.05/sq yd	1981
Irrigation systems				
	South Platte, Colo.	sq ft	0.35-0.70/sq ft	1976
	Corte Madera, Calif.	sq ft	0.60/sq ft	1978
	Cucamonga, Calif.	sq ft	0.25/sq ft	1973

* Costs other than those denoted B (bid price) are estimates.
** Not available.

Table 17

Selected Recreation Features Incorporated in

Flood Control Channel Projects

Project	Hike, bike trails	Picnic areas	Playgrounds, game fields	Nature study areas and trails	Lakes for fishing, boating	Swimming and wading pools	Equestrian trails	Overlooks	Fishing structures, access areas	Amphitheaters and bandstands	Campgrounds	Pavilions/plazas	Boat ramps	Canoeing/rafting
Fourmile Run, Md.	X													
Ellicott Creek, N.Y.	X	X	X					X						
Flint River, Mich.	X					X					X	X	X	X
Sabine River, Tex.	X													
San Antonio River & Tribs., Tex.	X	X			X									
Boggy Creek, Tex.	X	X		X										
Chillicothe, Ohio	X	X	X					X	X					
Hocking River, Ohio	X			X					X					
Tenmile Creek, Pa.	X													
Sandy Lick Creek, Pa.	X													
Indian Bend Wash, Ariz.	X	X	X	X	X	X	X				X	X		
Little Blue River, Mo.	X	X	X		X				X					
Ballona Creek, Calif.	X													
Cucamonga Creek, Calif.	X	X					X							
New River, Ariz.	X	X					X							
Tujunga Wash, Calif.	X													
Mill Creek, Ohio	X	X												
Miss. River State Park, Ark.	X	X						X	X	X				
Threemile Creek, Ala.	X	X	X											
South Platte, Colo.	X						X	X						X
Chartiers Creek, Pa.	X													
Souris River, N.D.	X	X	X	X		X		X						
South Fork Zumbro River, Minn.	X	X	X	X					X					
Walnut Creek, Calif.	X	X												

Table 18

Trails Incorporated in Flood Control Channel Projects

Project	District	Type of Surface	Cost ($ per sq yd)*	Base Year
Hike and Bike Trails				
Chartiers Creek, Pa.	Pittsburgh	Bituminous	9.50 (B)	1975
Fourmile Run, Md.	Baltimore	Concrete Bituminous	12.00 5.97 (B)	1972 1980
Ellicott Creek, N. Y.	New York	Asphalt/concrete	11.20	1982
South Platte River, Colo.	Omaha	Regular concrete, 8 ft × 4 in.	10.00	1983
Flint River, Mich.	Detroit	Scored concrete	45.00	1976
Flint River, Mich.	Detroit	Regular concrete	22.50	1976
Equestrian Trails				
Cucamonga Creek, Calif.	Los Angeles	Graded soil	1.80	1973
South Platte River, Colo.	Omaha	Graded soil	0.70	1976

* Costs other than those denoted B (bid price) are estimates from project General Design Memorandums.

Table 19

Selecting Features to Achieve Environmental Objectives

ENVIRONMENTAL FEATURE	LIMIT BED AND BANK EROSION	AVOID BED AGGRADATON	PREVENT GROUND-WATER LOWERING	IMPROVE LOW-FLOW CONDITIONS	IMPROVE WATER QUALITY	PRESERVE FISH HABITAT	IMPROVE AQUATIC HABITAT DIVERSITY	REDUCE LOSS OF RIPARIAN VEGETATION	IMPROVE TERRESTRIAL HABITAT DIVERSITY	MITIGATE WETLANDS	IMPROVE INSTREAM AESTHETICS	IMPROVE STREAMSIDE AESTHETICS	IMPROVE INSTREAM RECREATION	IMPROVE STREAMSIDE RECREATION
SELECTIVE CLEARING AND SNAGGING		O	O	O	O			O	O		O		O	O
TRADITIONAL CLEARING AND SNAGGING		O												
LOW- AND NORMAL-FLOW CHANNELS		O		O	O		O				O		O	
FLOODWAYS AND IMPASS CHANNELS				O										
MEANDERING ALIGNMENTS	O						O				O			
POOL AND RIFFLE GRADES				O	O	O	O				O		O	
SINGLE BANK MODIFICATION	O				O	O	O	O	O		O	O		O
GRADE CONTROL STRUCTURES	O													
ARMOR	O					O	O				O			
RIGID LININGS	O													
BANK PROTECTION	O	O												
INSTREAM HABITAT STRUCTURES				O	O	O	O				O		O	
WATER LEVEL CONTROL STRUCTURES			O	O	O	O	O				O		O	
FISHWAYS						O								
SUBSTRATE CONSTRUCTION	O					O	O							
OXBOW AND BENDWAY MAINTENANCE			O		O	O	O			O	O		O	
GREENTREE AREAS			O					O	O	O		O		O
VEGETATIVE PLANTINGS	O							O	O			O		
PLACEMENT AND SHAPING OF SPOIL									O	O		O		
PRESERVATION OF CUTOFF ISLANDS								O	O			O		O
SEDIMENT TRAPS		O		O							O			
SCHEDULING WORK FOR ENVIRONMENTAL REASONS						O							O	
VEGETATIVE BUFFER STRIPS	O	O			O	O		O	O			O		O
REVEGETATION OF DISTURBED AREAS	O	O						O	O			O		
SPECIAL ARCHITECTURAL DESIGNS											O	O		
SPECIAL MATERIALS AND FINISHES											O	O		
WATER DISPLAYS											O	O		
SPECIAL STRUCTURES FOR STREAM-BASED RECREATION													O	
TRAILS														O
PICNIC AREAS, CAMPGROUNDS, ETC														O
PLAYGROUNDS, SPORT FIELDS, ETC														O
"PASSIVE" RECREATIONAL AREAS														O

NOTE "O" INDICATES THAT THE ENVIRONMENTAL FEATURE HAS BEEN OR CAN BE USED TO ACHIEVE THE ENVIRONMENTAL GOAL

Table 20

Suitability of Features for Various Preproject Stream and Watershed Characteristics

	SELECTIVE CLEARING AND SNAGGING	LOW AND NORMAL FLOW CHANNELS	FLOODWAYS AND BYPASS CHANNELS	MEANDERING ALIGNMENTS	POOL AND RIFFLE GRADES	SINGLE BANK MODIFICATION	GRADE CONTROL STRUCTURES	ARMOR	*RIGID LININGS*	BANK PROTECTION	INSTREAM HABITAT STRUCTURES	WATER LEVEL CONTROL STRUCTURES	FISHWAYS	SUBSTRATE CONSTRUCTION	OXBOW AND BENDWAY MAINTENANCE	GREENTREE AREAS	VEGETATIVE PLANTINGS	PLACEMENT AND SHAPING OF SPOIL	PRESERVATION OF CUTOFF ISLANDS	SEDIMENT TRAPS	SCHEDULING WORK FOR ENV REASONS	VEGETATIVE BUFFER STRIPS	REVEGETATION OF DISTURBED AREAS	SPECIAL ARCHITECTURAL DESIGNS	SPECIAL MATERIALS AND FINISHES	WATER DISPLAYS	SPECIAL STRUCTURES FOR STREAM-BASED RECREATION	TRAILS	PICNIC AREAS, CAMPGROUNDS, ETC	PLAYGROUNDS, SPORT FIELDS, ETC	"PASSIVE" RECREATIONAL AREAS	*CAMPGROUNDS*
STREAM REACH CHARACTERISTICS																																
CHANNEL PATTERN																																
BRAIDED		□		□	□			□			□	□		□	□					Δ												
MEANDERING			O	O																												
STRAIGHT TO SINUOUS				Δ																												
POOL-RIFFLE SEQUENCE																																
WELL DEVELOPED					O																											
NOT WELL DEVELOPED					Δ																											
SEDIMENT TRANSPORT																				O												
HIGH BEDLOAD		□		Δ	Δ			Δ			□	□		□	Δ					O												
HIGH SUSPENDED LOAD											Δ				Δ																	
MODERATE TO LOW		O									O				O																	
CHANNEL STABILITY																																
STABLE								O																								
UNSTABLE		Δ		Δ	Δ			Δ				Δ		□												□						
SUBSTRATE																																
BEDROCK			Δ					□			Δ																					
GRAVEL								O			O																					
SAND		Δ			□			□			Δ	Δ		□						O												
SILT-CLAY-ORGANIC								Δ						□																		
BANK COHESIVENESS																																
HIGH																																
LOW				Δ	Δ		Δ																									
SLOPE																																
HIGH (>0.04)											□	□				□																
MODERATE (0.002-0.04)											O																					
HIGH (<0.002)				Δ							Δ																					
SETTING																																
URBAN																□																
RURAL																										□						
DISCHARGE (BANKFULL)																																
LOW <1,000 CFS											O																Δ					
MED. 1,000-10,000 CFS											Δ																					
HIGH >10,000 CFS								Δ			□																					
ANNUAL FLOW REGIME																																
EPHEMERAL		□			□						□	□	Δ	□	Δ	□										Δ						
EXTREME VARIATION											Δ																					
NORMAL															O																	
WATER QUALITY, CHEMICAL																																
POOR		□									□	Δ	□	□	Δ											Δ	□					
FAIR																																
GOOD																																
FISHERY																																
LITTLE OR NONE											□		□	□																		
COLD WATER											O																					
WARM WATER											Δ																					
WATERSHED CHARACTERISTICS																																
LAND USE																																
URBAN											Δ					□																
AGRICULTURAL											Δ											O										
RANGELAND																																
FORESTED																O																
PRECIPITATION																																
ARID												Δ		Δ		□	Δ						□									
SEMIARID											Δ					Δ	Δ															
HUMID																O	O															
WINTER TEMPERATURE																																
COLD (STREAMS *FREEZE OVER*)											Δ	Δ																				
MODERATE TO WARM																																
TERRAIN																																
MOUNTAINOUS			□	Δ												□		Δ														
HILLY											O																					
FLAT																O																
WATERSHED EQUILIBRIUM																																
RELATIVELY UNDISTURBED											O																					
HIGHLY *DISTURBED*		Δ			Δ			Δ			Δ		Δ																			

NOTE □ — HAS PROVEN UNSUCCESSFUL *IN MOST CASES. LIKELY TO BE UNSUCCESSFUL DUE TO PHYSICAL* CONSTRAINTS, OR INAPPROPRIATE

Δ — POTENTIAL PROBLEMS LIKELY TO BE ENCOUNTERED. SUCCESSFUL APPLICATIONS MAY REQUIRE SPECIAL DESIGNS OR CONSIDERABLE MAINTENANCE

O — HAS OFTEN PROVEN SUCCESSFUL.

BLANK — LITTLE OR NO INFORMATION, OR CONDITIONS NOT A CONSIDERATION

APPENDIX A: GLOSSARY

<u>aggradation</u> Deposition of sediment in a channel, on a floodplain, or other surface in sufficient quantity to increase local elevation.

<u>annual series</u> The discharge record consisting of the greatest discharge each year during the period of record.

<u>armor</u> A coarse layer of gravel or cobble that develops on a streambed through winnowing away of fines.

<u>baffle</u> A plate, wall, screen, or other device to deflect or impede flow.

<u>bedforms</u> Ripples, waves, dunes, and related forms that develop under various flow conditions on the beds of alluvial streams with significant bedload transport.

<u>bedload</u> Sediment, usually sand size or larger, that is transported along the bed by rolling, skipping, dragging, or saltation.

<u>benthic</u> Of, pertaining to, or related to the bottom of a stream or other body of water.

<u>berm</u> A terrace or ledge formed within a channel at base of the streambank. Also a terrace or ledge cut on a slope or embankment to divert water or intercept sliding earth.

<u>bollards</u> Heavy post and chain fixtures used to exclude wheeled vehicles from protected areas.

<u>braided channel</u> A channel pattern characterized by numerous intertwined channelways, steep gradient, and coarse bed material.

<u>bypass channel</u> A short flood diversion channel constructed to bypass a tortuous reach of natural stream or features of special interest such as wetlands. Bypass channels may be constructed to convey all flows or flood discharges only.

<u>check dam</u> A low dam constructed of logs, loose rock, or other material to control water flow and check erosion.

<u>cobble</u> Gravel and stones that have been rounded by abrasive action of flowing water or waves.

<u>coldwater stream</u> Headwater stream located at an elevation or latitude sufficient to produce water temperatures low enough to support salmonid fishes.

<u>cross-sectional area</u> The area of a section of a channel at right angles to the direction of flow.

<u>cutoff island</u> An island created in a bend or meander by excavating a bypass or diversion channel across the meander neck.

<u>debris basin</u> A basin constructed, usually at the mouth of a canyon or steep mountain stream, to trap sediment or debris that would clog or damage a flood channel.

Denil fishway A fishway design that uses side and bottom vanes inside a steep trough to create countercurrents that slow velocities.

drop structure A grade control structure which provides for a vertical drop in the channel invert between the upstream and downstream sides.

ephemeral stream A stream that flows only during or immediately after periods of rainfall or snowmelt.

equilibrium A condition of fluvial systems in which slope, discharge, channel pattern, channel morphology, and sediment supply are balanced.

evapotranspiration The combined moisture loss from evaporation and transpiration.

fabridam A dam constructed of fabric and rubber that can be inflated with air or water.

fish ladder A fishway that provides passage over or around a vertical obstruction.

fishway A structure designed to allow fish passage around, over, or through obstacles.

flap gate A gate hinged at the top and allowing flow in only one direction.

flood channel Any partially or completely excavated channel intended to convey flows above normal discharges. Flood channels may be sized to convey any return interval discharge above the 2-year or other normal bankfull discharge.

flood diversion channel (See floodway).

floodway A natural or constructed channel which conveys flood flows.

flume An open channel constructed of wood, steel, or reinforced concrete and used to convey water for various purposes, including grade control.

form liner A liner for concrete forms designed to produce a special finish.

gabions Rock-filled wire cages used on streams for erosion protection and construction of dams and other structures.

grade control structure Any of several types of structures used to control erosion on channels with steep grades (see stabilizer, drop structure, and flume).

greenbelt A linear park, usually located along a stream corridor or other right-of-way.

greentree reservoir A shallow reservoir in which water levels are manipulated for wildlife and timber production.

headcut A point of abrupt change in the longitudinal profile of a stream. Headcuts typically migrate upstream through time.

Hells Gate fishway A fishway design which combines principles of the Denil fishway with a vertical slot design.

high flow channel A channel design employing a subchannel for normal and low flows and high flow berms that are flooded on an infrequent basis. When the existing natural channel is used for the subchannel, excavation may take place from one or both sides, but the existing channel is disturbed as little as possible.

hydraulic radius Equal to A/P, where A is cross-sectional area and P is wetted perimeter. Roughly comparable to average depth in wide, shallow streams.

intermittent stream A stream which flows most of the time, but ceases to flow seasonally or occasionally because bed seepage and evaporation exceed the supply of water.

invert The bed of a channel or culvert.

knickpoint (Same as headcut).

low flow channel A subchannel designed to concentrate low flows for biologic, recreation, or aesthetic reasons.

macroinvertebrates Large invertebrates found in streams and consisting largely of larval insects, worms, and related organisms.

Manning's n A resistance coefficient used in the Manning equation for uniform steady flow, $V = \frac{1.49}{n} R^{2/3} S^{1/2}$ where V is mean velocity, R is hydraulic radius, and S is slope, all expressed in English units.

meander A broad, looping bend in a stream channel.

meander amplitude Meander width, usually expressed as a multiple of stream width (see Figure 20).

meander wavelength The average distance from crest to crest, or trough to trough, in a series of meander waves (see Figure 20).

natural stream channel A channel whose alignment, dimensions, cross-sectional shape, and grade have not been intentionally modified by humans.

oxbow lake A lake formed in a former stream meander that has been abandoned naturally or cut off during channel construction for navigation or flood control purposes.

paddleway A reach of a low gradient stream developed for canoeing.

point bar A crescent shaped bar of coarse sediment built out from the convex bank of a meander.

pool Topographically low area produced by scour and which generally contains fine-grained sediments. Pools are usually associated with point bars on meandering streams.

pool and orifice fishway A fishway designed with a series of baffles or weirs with openings or orifices in them, through which fish pass.

pool and weir fishway A fishway consisting of low weirs in series. Fish ascend by jumping from pool to pool.

propagule Seed, cutting, tuber, bulb, rhizome, or other vegetative component used to propagate plants.

regime theory Theory that channel morphology can be related quantitatively to discharge for streams that are stable or in equilibrium.

resistance coefficient An empirically derived coefficient used in uniform flow equations to account for flow resistance.

riffle A topographically high area in a channel created by the accumulation of relatively coarse-grained sediments.

riparian vegetation Vegetation along the bank of a watercourse.

salmonid or salminoid Collective term referring to salmon, trout, grayling, or white fish, all of which prefer coldwater environments.

saltation Movement of sediment along a channel bed by intermittent bouncing.

SCS curve number Values ranging between 1 and 100 that are used in calculating runoff rates by the SCS method. The more impervious a surface is, the higher the curve number.

sediment basin A basin constructed to trap sediment eroded from a slope or being transported by a stream.

selective clearing and snagging A modified version of clearing and snagging which limits the types and amount of snags and vegetation removed and uses construction methods that create minimal disturbance.

shear stress Stress imposed on the streambed and banks by flowing water.

sill A low dam designed to prevent erosion or create pools for fish habitat.

sinuosity A measure of meandering calculated as a ratio of stream length to valley length.

stable channel A channel which neither erodes nor deposits over a period of several years; a graded stream.

stabilizer A low sill across a channel, used to prevent bed erosion (see Figure 15a).

stilling basin An enlarged area in a channel that is deep enough to reduce flow velocity.

stream power The product of a stream's discharge rate (Q) and slope (S).

subchannel A channel inside a larger flood control channel that is used to convey low and/or normal flows (see low flow channel).

substrate Surface to which stream biota adhere or within which they live.

suspended load That portion of a stream's sediment load that is carried in suspension.

thalweg A line connecting the deepest points along a channel.

through flow That part of storm runoff that moves through the soil (same as interflow).

threshold A point or value which, if exceeded, creates either positive or negative feedback. Positive feedback destroys equilibrium conditions in fluvial systems, whereas negative feedback tends to restore them.

toe slope The lowest portion of a bank slope where it merges with the channel invert.

tractive force (See shear stress).

turbidity Reduction in transparency caused by suspended solids or colloidal liquid droplets.

unit discharge Discharge rate per unit width (Q/W).

Universal Soil Loss Equation (USLE) An equation used to calculate average annual sheet and rill erosion from a land surface area.

warmwater stream A stream with water too warm to support salmonid fishes.

water control structure A device, such as a weir or gated structure, used primarily to control water level.

wing deflector A low structure used to create scour holes for fish habitat purposes (see Figure 38).

APPENDIX B: GENERAL PROCEDURE FOR THE DESIGN OF CONTROL CHANNEL PROJECTS

I. Establish Project Objectives

  A. Flood damage reduction--level of protection desired

  B. Environmental

    1. Water quality
    2. Recreation
    3. Fish and wildlife

II. Choose Alternatives for Achieving Project Objectives

  A. Nonstructural

  B. Structural

    1. Reservoirs

    2. Levees

    3. Flood control channels

III. Evaluate Alternatives and Select General Plan

IV. Detailed Project Design for Flood Control Channels

  A. Data collection and analysis, existing conditions

    1. Watershed conditions

      a) Climate
      b) Topography
      c) Soils/geology
      d) Sediment yield
      e) Land use/cover (existing and recent changes)
      f) Hydrology

    2. Stream and floodplain (each reach)

      a) Hydrology

        i. Generate flood frequency series
        ii. Determine corresponding stage data
        iii. Calculate flow duration curves (hydrographs)

      b) Hydraulics

        i. Identify resistance components and determine existing n values at various discharges
        ii. Determine amount and size distribution of bedload and suspended load

c) Geomorphology

   i. Survey cross section and existing channel grade
   ii. Establish relationship of cross-section geometry to discharge using Equations 22 and 23
   iii. Measure pool-riffle spacing and meander geometry and relate to discharge and channel width (using formulas tabulated in paragraph 60)
   iv. Evaluate stability of bed and banks
   v. Measure size distribution of bed and bank material
   vi. Measure cohesiveness of banks
   vii. Identify and map locations of "hardpoints" in bed or bank

d) Stratigraphy (from test borings, exposed sections)

   i. Determine stratigraphic sequence
   ii. Describe stratigraphic units in detail
   iii. Establish average depth to seasonal water tables

e) Existing structures

   i. Types
   ii. Locations
   iii. Design
   iv. Scour and deposition patterns

f) Ice

   i. Recorded thickness
   ii. Average dates of freeze and breakup
   iii. Damage
   iv. Flow patterns and blockages

g) Ecology

   i. Map riparian vegetation and locate and identify unique or valuable trees
   ii. Describe terrestrial ecology
   iii. Describe aquatic ecology

h) Water quality

   i. Turbidity
   ii. Chemical
   iii. Temperature

i) Aesthetic resources - identify, describe, and photograph major components

j) Cultural and recreational resources - identify and describe major resources, with particular attention to historical and archeological components

B. Flood control channel design

1. Fix exact location and alignment geometry of channels (for meandering alignments, follow procedure in paragraphs 165-169)

2. Hydraulic design

   a. Rapid flow channels - use lined channels; choice of environmental features severely limited (for design guidance see OCE (1970) or SCS (1977)

   b. Tranquil flow channels

      i. Select best combination of channel cross-section alignments and construction techniques to meet flood control and environmental objectives (use selection process described in Part V)

      ii. Select additional features to meet environmental objectives (use matrices in Part V)

      iii. Establish downstream water surface elevation and the water surface control line, including freeboard

      iv. Select <u>n</u> values for each reach

      v. Size channel

      vi. Check channel stability (if unstable, stabilize by one or more of the following: adjust cross section; adjust grade, line, or armor channel; provide grade control; provide bank protection)

3. Review design for maintenance consideration; adjust if necessary

4. Review design for aesthetics; adjust if needed

C. Design environmental features of project that are not part of the flood channel proper

D. Develop detailed cost estimates; if cost too high, modify project design beginning at Step IVB

APPENDIX C: CHECKLIST OF DATA SOURCES

Type of Data	Sources
1. Watershed conditions	
a. Climate	National Weather Service climatic summaries; U. S. Weather Bureau Technical Paper 40, "Rainfall Frequency, Atlas of the United States"
b. Topography	USGS topographic maps; city and county topographic surveys; aerial photos
c. Soils/geology	County soil surveys, state geologic survey sheets; aerial photos
d. Sediment yield	Local SCS office; state natural resource surveys
e. Land use/cover	Local planning agencies, USGS 1:250,000 land use quadrangles (LUDA sheets); aerial photos
f. Hydrology	(See sources under climate); USGS National Water Data Exchange (NAWDEX) file; drainage district maps
2. Stream and Flood Plain	
a. Stream morphology	Large-scale topographic maps; aerial photos; field measurements; close-range photography; drainage district records
b. Streambank stratigraphy	Exposed sections; construction test borings; soil maps; drainage district records
3. Historic data on land use, floods, prior modifications	Drainage districts, courthouse records, old surveys, longtime residents, archives, newspaper files
4. Unique resources	
a) Historical sites, including prehistoric	National Register of Historical Places, local historians and historical societies
b) Trees	National and state tree registers
c) Rare and endangered species	List of Rare and Endangered Species; Audubon Society; Sierra Club; Soil Conservation Society of America

APPENDIX D: SPECIFICATIONS FOR CONSTRUCTION OF CLAY BLANKET*

Fills

1. Embankment for the channel blocks and fills other than channel fill shall be constructed to the plan grade and cross section shown on the design drawings without additional allowance for shrinkage of the fill. Materials shall be obtained from required excavation. The classification of any material, rather than the origin, will determine where it may be used. Material shall be classified in accordance with the procedures specified hereinafter and shall be placed at the proper locations as approved by the Contracting Officer.

Materials

2. Impervious material shall be fine-grained materials of low permeability, consisting of clays (CH), clays (CL), or silts (ML), and shall be free of plant growth, roots, and humus. The particle size of impervious material shall be such that a minimum of 50 percent of the soil particles shall pass a U. S. Standard No. 200 screen, and where available, shall be material classified as CL or CH on the plasticity chart of the Unified Soil Classification Chart, Revised 1960, and published in Waterways Experiment Station Technical Memorandum 3-357.

3. Clay blanket material shall be impervious material as defined above, but restricted to clays (CH) and clays (CL) with a minimum liquid limit of 40.

Placement and Compaction

4. Clay blanket shall consist of clay blanket materials placed to the lines and grades shown, at the locations indicated as determined by the Contracting Officer. Material shall be placed in one lift so that

---

* Source: U. S. Army Engineer District, Kansas City, 1972.

the final compacted thickness is a minimum of 12 in. Material shall be compacted with two passes of a crawler tractor.

Quality Control

Sampling, testing, and approval of materials

5. Tests, except as otherwise specified herein, shall be performed by the Contractor as a part of the quality control program. The Contractor shall obtain representative samples of the materials required for the tests. In addition, and upon request, samples shall be submitted to the Contracting Officer for Government testing. Tests performed on materials which do not meet specifications will not be counted as part of the required tests. Tests shall be performed in accordance with the following requirements.

- a. Atterberg limits shall be determined in accordance with the Engineer Manual (EM) 1110-2-1906, Appendix III.
- b. The maximum dry density and the optimum moisture content of the impervious material shall be determined in accordance with EM 1110-2-1906, Appendix VI, paragraph 2. A minimum of four points shall be run for each curve. Additional points shall be added to fully develop the curve in the range of specified moisture content.
- c. Density tests on compacted materials shall be taken in the field in accordance with ASTM Standard D 1556.
- d. Water content tests based on oven-dry specimens shall be in accordance with EM 1110-2-1906, Appendix I.

Initial tests

6. The Contractor shall test all material from required excavations that he plans to utilize as impervious fill. The location and elevation sampled shall be carefully selected to truly represent the material to be utilized and to show the range in properties of these materials. The Contractor shall perform the following minimum initial tests prior to the actual placement of material. Additional tests shall be run whenever a variation in material occurs.

Type of Test	Material	Number of Tests
Compaction test	Impervious	As required to develop a full family of compaction curves for each material source
Atterberg limits	Impervious	One per compaction test and as required to delineate acceptability of material prior to placement in the embankment and fill
Atterberg limits	Clay blanket material	One per 1000 cu yd of material in loose lift
Moisture content	Impervious	As required for control

APPENDIX E: PROPOSED LANDSCAPING MAINTENANCE REQUIREMENTS FOR WALNUT CREEK FLOOD CONTROL PROJECT*

Description

1. Trees and shrubs have been planted and irrigation systems installed at various sites along Walnut Creek and its tributaries. Aesthetic and functional considerations were requisites in the design and planting of these sites and should be the guiding criteria in their continuing maintenance.

Maintenance

2. Landscaped areas should be maintained as originally designed unless experience indicates that changes are required. After the expiration of maintenance required under the landscaping contract, it is the responsibility of the Superintendent to maintain landscaped and planted areas on a continuing basis. Some specific requirements are:

- _a_. From May through October, watering is required in an amount sufficient to ensure moisture in the root zone of trees and shrubs to maintain good growing conditions. Sidewalls of water basins at the base of trees and large shrubs should be maintained to a height between 4 to 6 in.
- _b_. Grass and weeds should be hoed out or trimmed to a 5-ft radius around trees and large shrubs as a fire guard. In lieu thereof, grass and weeds may be controlled by use of herbicides as authorized by local ordinance and appropriate regulatory agencies. Herbicides must be applied carefully to prevent damage to plantings.
- _c_. Plantings should be fertilized to the extent necessary to maintain vigorous growth.
- _d_. Trees and shrubs should be pruned and trimmed to preserve aesthetic value and promote healthy growth.
- _e_. Tree stakes and ties should be checked at intervals to prevent girdling. Ties should be loosened as trees grow and replaced as old ties break. Ties should be loose

---

* Source: U. S. Army Engineer District, San Francisco 1979.

enough to permit movement and growth. Stakes and ties should be removed when a tree no longer needs support.

f. Dead trees, shrubs, and other plantings should be replaced as necessary to preserve the aesthetic and functional value of the landscaping.

APPENDIX F: INDEX

END

FILMED

9-85

DTIC